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REPORT FOR WORK ORDER NO. 5

PHOTOGRAPHIC CONSULTING SERVICES FOR EARTH RESOURCES PROGRAM

AT

NASA-GODDARD SPACE FLIGHT CENTER

CONTRACT NASW-2317

Submitted to
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Earth Observation Programs
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PHOTOGRAPHIC CONSULTING SERVICES

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REPORT ON WORK ORDER NO. 5

Summary

A comparison of prints from ERTS photography revealed significant differences in the image quality produced at GSFC, the EROS facility at Sioux Falls, and Eastman Kodak in Rochester. Based on this survey photographic quality was improved significantly at Sioux Falls, and improvements were suggested for optical and contact printers at the GSFC.

Based on a test in which 365 meters of Eastman Electron Recording Film (ESTAR Base) SO-438 were processed the 1-sigma variation in process control from all sources is about ± 0.04 at a density of 1.0. Variations from film and from processing were approximately equal contributors to the overall tolerance.

Distortion produced by the Kodak Colorado printer at GSFC covers a range of about 0.04%, a small value compared to that caused by other factors in the ERTS system. The edge fringing inherent in the color film materials used at GSFC also seems to be a small factor in the unsharpness of ERTS color prints.

MTF and granularity measurements were made on processed film samples supplied by GSFC. MTF values were above 0.70 out to 42 cycles/mm for all stages of contact printing in the ERTS system.

TABLE OF CONTENTS

Introduction

This report summarizes tasks accomplished under Work Order No. 5 for the NASA-Goddard Space Flight Center from April 1972 to February 1973. Although technical services by Kodak continue to be provided for GSFC under this work order, it seems useful to report on those tasks completed to date. All of the calculations, test data, and film images derived from this work were immediately given to personnel at the GSFC photographic laboratory for their review and action. This insured timely consideration of the test results prior to issuing a formal report.

Included in this summary are the results of the inter-laboratory survey using ERTS photography that was reported separately on 7 February 1973. In addition, details are given regarding measurement of film granularity and MTF, printer distortion, sources of variability in processing the film from the Electron Beam Recorder, and sensitometric and sharpness factors in the color film system used at GSFC.

During the 10 month period of Work Order 5 specific recommendations for improved performance were made directly to the laboratory personnel and were noted in the monthly reports to NASA Headquarters. Microdensitometer service and other technical photographic analysis will continue for the GSFC during 1973.

Comparison of Printing Facilities Using ERTS Photography

Summary

A survey was made of prints produced in photographic laboratories at Goddard Space Flight Center and Sioux Falls. At Sioux Falls, losses from flare light and low resolution were substantially reduced in a second test run on 10 January 1973. Adjustments are needed to improve off-axis resolution in both optical and contact prints made at GSFC. The fidelity of tone and geometric reproduction is similar in all printers in this survey, and is probably satisfactory for most users of ERTS imagery. However, precise radiometric measurements are difficult from densitometry of ERTS pictures. The requirements should be reevaluated for sharpness, granularity, tone scale, and printing contrast in the 70mm N-2 print used to make 9.5-inch enlargements.

Because of the need for timely distribution of these test results, the data and conclusions from this work were issued as a separate report on 7 February 1973.

Introduction

An evaluation of printing and processing facilities for handling ERTS photography was initiated at Goddard Space Flight Center on 13 October 1972 in a meeting of personnel from several ERTS laboratories. With assistance from NASA management and Kodak engineers, test materials and procedures were defined that would yield a quantitative measure of photographic quality in contact and enlarged black and white transparencies. A representative ERTS scene image was produced on Eastman Electron Recording Film (ESTAR Base) SO-438 using the Electron Beam Recorder at GSFC. On the same film, Kodak made a special test frame containing gray scales, low contrast tribar targets, and log periodic patterns for measurement of modulation transfer function.

The test images were printed at GSFC, Kodak, and Sioux Falls in November 1972. Representatives from the NOAA laboratory at Suitland, Maryland attended the original planning meeting but no prints were made at this laboratory. A second print was made at Sioux Falls on 10 January 1973 after improvements were made to their Bessler enlarger.

This report describes the analysis made by Kodak from the printed pictures and test frames.

Procedure

The test scene on SO-438 film was the red light image of the Seattle, Washington area recorded by the Return Beam Vidicon on 29 July 1972. Although the gray scale at the edge of the scene runs from 0.12 to 2.02, scene limits measured with a 1.5mm aperture are D min 0.14 and D max 1.71; average scene density is near 1.0. This scene includes snow, clouds, water, and both rural and urban areas. An image area showing suburban Seattle located about half way to the edge of the scene was enlarged from the original film and all print films.

The test frame is shown in Figure 1 along with density data for the areas indicated. From this frame we can measure modulation transfer function and low contrast tribar resolution in two orthogonal directions on axis and at each corner. MTF is calculated by computer analysis of log periodic bar patterns. Eight small squares plus the background density near the middle of the frame comprise a 9-step gray scale for measurement of tone reproduction. Tone distortion is measured by comparison of densities from two patches near each edge of the frame with similar patches in the center.

Four large squares permit measurement of granularity at four density levels, but these areas were not used in this test. Geometric distortion was measured by comparing the length of the full tribar pattern in the center of the frame with the same length in each corner.

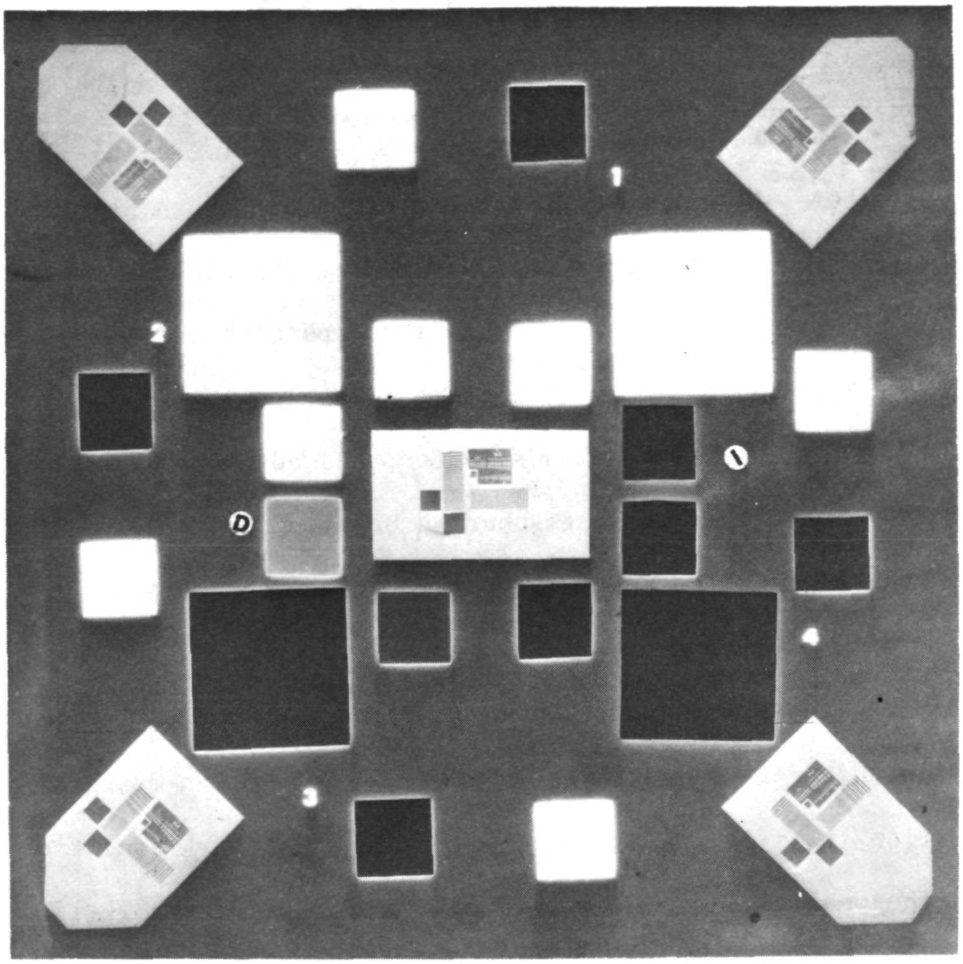


FIGURE 1

P-1 ORIGINAL TEST FRAME
KODAK SO-438 FILM

Central Gray Scale

	Density	
A	0.07	
B	0.28	
C	0.49	
D	0.83	
E	0.96	Background
F	1.16	
G	1.56	
H	2.12	
I	2.47	

Numbered Off-Axis Test Areas

Corner or Edge	Edge Uniformity Patches	Large Granularity Test Patch	*2.4:1 Tribar Targets Limiting Resolution line pairs/mm	
1	0.25	0.26	H	188
	1.60		V	188
2	0.27	0.48	H	188
	1.59		V	178
3	0.27	1.55	H	168
	1.62		V	200
4	0.26	2.48	H	158
	1.58		V	178
Center	----	----	H	200
			V	200

* Background density = 0.93; tribar density = 0.55

Test Results

The flow chart in Figure 2 describes the kinds and sizes of film used in the test and notes the printing equipment used by each laboratory. Prints were made by Goddard Space Flight Center (GSFC) on KODAK Aerial Duplicating Film (ESTAR Base) SO-467, while the Kodak and Sioux Falls laboratories used KODAK Fine Grain Aerial Duplicating Film 2430 (ESTAR Base). One contact N-2 was made in Rochester on KODAK Aerographic Duplicating Film 2420 (ESTAR Base). The circled code numbers identify each 9.5-inch print and are used for this purpose on all subsequent illustrations.

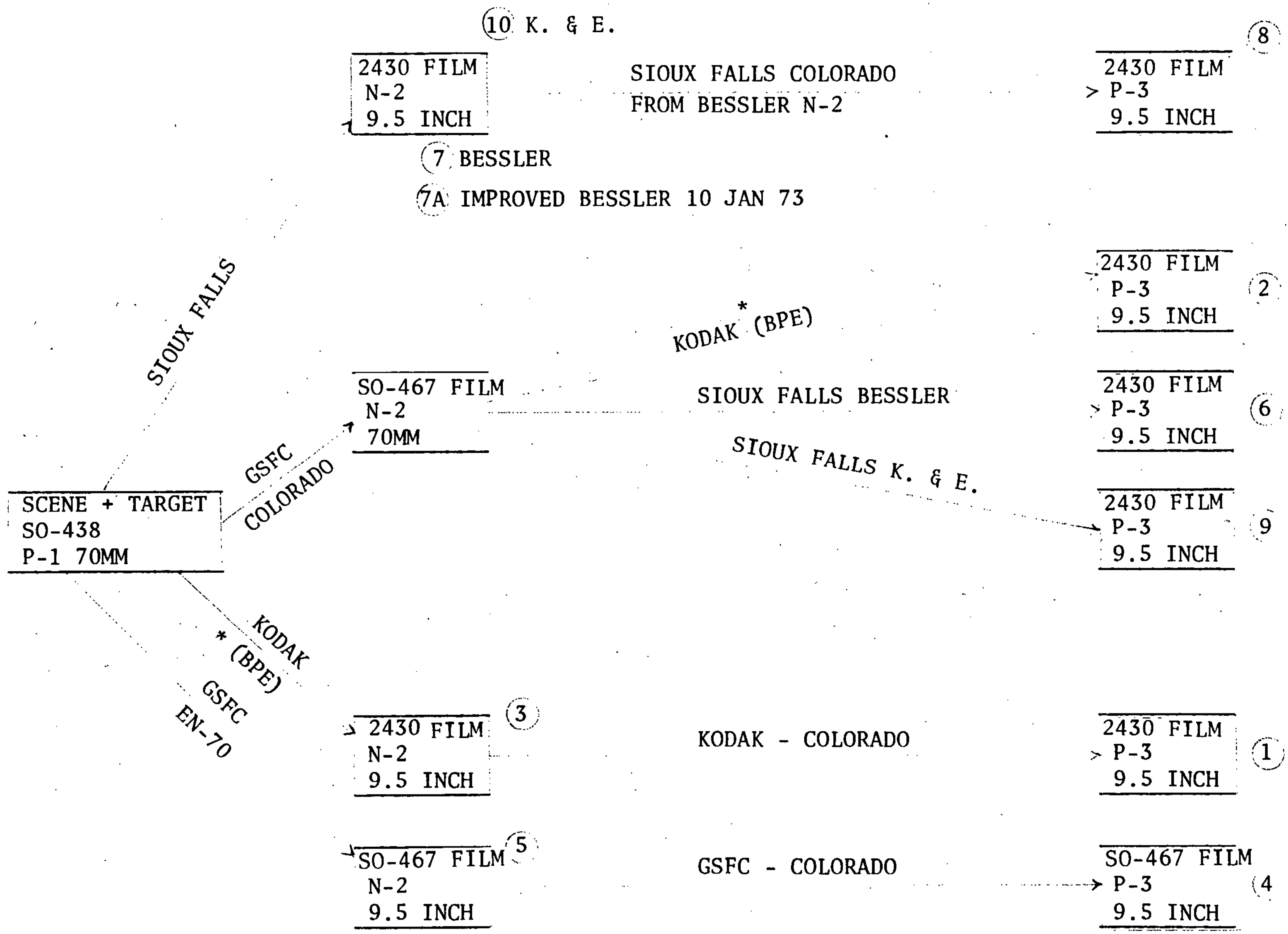
Resolution

Tribar resolution measured from a target of 2.4:1 contrast is a common and useful method for determining the image sharpness of aerial systems. Table I lists resolution values read by an experienced observer using a 35X microscope and diffuse illumination. Values marked with an asterisk were measured on 70mm P-1 and N-2 images but refer to the resolution that would be observed on 9.5-inch prints made with no losses at 3.369X. Resolution values for horizontal and vertical orientations were averaged and are plotted in Figure 3.

Those enlargements made directly from the P-1 original are limited to 25 line pairs per mm by the combination of lens and film quality. Note, however, that contact prints (N-2) made from the same P-1 original are also limited to the equivalent of 25 lp/mm. In absolute terms, a low contrast input of 200 lp/mm is reduced to

ERTS INTERLABORATORY SURVEY

FIGURE 2



* BPE IS THE KODAK BEACON PRECISION ENLARGER.

TABLE I

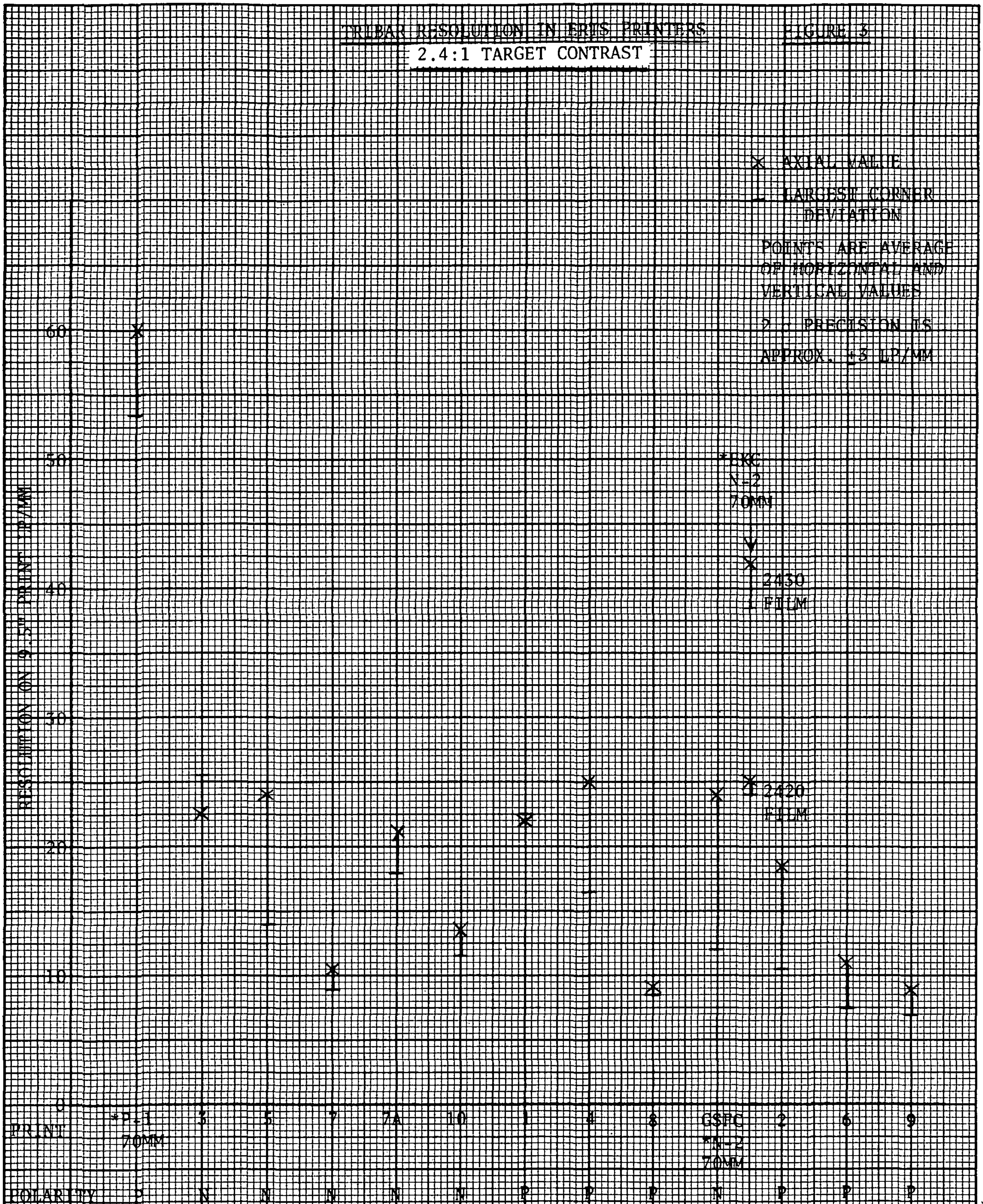
ERTS PRINTERS
TRIBAR RESOLUTION READINGS

Values are in line pairs per mm for a target contrast of 2.4:1.

Print No.	Printing System	Print Polarity	Tribar Orientation	Axial	CORNERS 1	2	3	4
1	EK P-3 from 9.5" EK N-2	P	H	23	21	21	22	22
			V	21	21	21	22	23
2	EK P-3 from 70mm N-2	P	H	18	9	12	10	10
			V	19	12	14	13	12
3	EK 9.5" N-2 from 70mm P-1	N	H	22	23	25	25	25
			V	23	23	26	26	25
4	GSFC P-3 from 9.5" N-2	P	H	26	21	19	22	20
			V	24	19	19	11	15
5	GSFC 9.5" N-2 from 70mm P-1	N	H	24	19	15	17	20
			V	24	15	14	11	14
6	SF-Bessler P-3 from 70mm N-2	P	H	9	8	10	8	9
			V	13	8	7	7	7
7	SF-Bessler 9.5" N-2 from 70mm P-1	N	H	10	16	13	10	14
			V	11	10	11	10	8
7A	SF-Improved Bessler 9.5" N-2 from 70mm P-1	N	H	20	18	19	20	22
			V	22	18	20	18	21
8	SF P-3 from 9.5" SF-Bessler N-2	P	H	7	16	10	10	11
			V	11	10	9	7	8
9	SF-K&E P-3 from 70mm N-2	P	H	7	7	7	7	7
			V	11	7	7	8	7
10	SF-K&E 9.5" N-2 from 70mm P-1	N	H	10	11	13	10	14
			V	17	12	14	15	12
N-2	GSFC 70mm contact print from P-1	N	*H	25	11	13	14	14
			*V	24	13	15	13	15
N-2	† EK 70mm 2420 film contact print from P-1	N	*H	25	23	23	25	25
			*V	25	23	26	26	25
N-2	† EK 70mm 2430 film contact print from P-1	N	*H	42	42	42	40	37
			*V	42	40	35	40	47
P-1	Original Test Target on Kodak SO-438 film	P	*H	60	56	56	47	47
			*V	60	56	53	60	53

* Resolution values are those that would be observed on a perfect 9.5 inch enlargement made with no losses at 3.369X.

† 2420 is KODAK Aerographic Duplicating Film 2420 (ESTAR Base)
2430 is KODAK Fine Grain Aerial Duplicating Film 2430 (ESTAR Base)



10 X 10 TO THE 1/2 INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.

80 lp/mm by contact printing and to 25 lp/mm by optical printing, but in both cases this limit is about the same test chart. Apparently for this target contrast the losses due to the enlarger lens at 25 lp/mm are approximately equal to the loss caused by the Kodak 2420 (or SO-467) film in contact printing at 80 lp/mm.

Both negatives made by GSFC on SO-467 film (5 and N-2) falloff in resolution at the corners. While the drop in sharpness on the optical print (5) might be expected, the loss at the edges of the contact N-2 is surprising. Apparently improper web tension or roller alignment on the Kodak Colorado printer at GSFC is causing a slight separation between original and print film at the edges of the 70mm strand. Adjustment to lower and more nearly equal tension on the supply and takeup strands of the P-1 should cure this problem. Examination of 5 of the 8 contact N-2 prints made by GSFC revealed low corner resolution (12 to 14 lp/mm) on all, and one showed double imagery even on axis. Parallel alignment between the drum and pressure roller should remove any slippage or chatter.

As a check on the potential quality of contact prints from a P-1 original, Kodak made 70mm N-2 prints using the Colorado printer on 2420 film (similar to SO-467 film) and 2430 film. Low contrast tribar resolution values from these prints are plotted on Figure 3 near the data from the GSFC N-2. The print on 2420 film showed the equivalent of 24-25 lp/mm uniformly at all 5 check points, while the

finer-grained 2430 film yielded about 40 lp/mm. Since the spacecraft scanning system limits resolution on 9.5 inch prints to a maximum of 15 lp/mm, it is not clear that use of 2430 film would give improved 70mm N-2 prints.

Even a small improvement in sharpness would be useful as the Kodak enlargement (2) made from the 70mm N-2 is poorer than the print (3) made directly from the P-1. Prints (1) and (4) made by contact from enlarged N-2's are also better than print (2).

All prints made at Sioux Falls (7), (10), (8), (6), and (9) show a resolution of about 10 lp/mm regardless of whether the P-1 or 70mm N-2 is used as a starting point. However, a later test (7A) made on 10 January 1973 after the Bessler enlarger had been modified, showed 21 lp/mm, a great improvement over the first test. These changes included correct placement of the condensers and light source, removal of the glass negative carrier, and precise alignment of the enlarging lens and film planes. An enlarging lens of higher quality is on order and when installed should yield an output close to 25 lp/mm as obtained at Kodak and GSFC.

Modulation Transfer Function

MTF is a more significant measurement than tribar resolution in that it gives information on image quality at all frequencies of interest to the system. In this test MTF was calculated for two orthogonal orientations on axis; these values were averaged to obtain

the curves shown in Figure 4. MTF test patterns were imaged at the corners but were not analyzed.

Figure 4 reveals three groups of curves:

P-1 and N-2	Original target and contact print
1, 2, 3, 4, 5	Enlargements made by Kodak and GSFC
6, 7, 8, 9, 10	Enlargements made by Sioux Falls in first test

The MTF of the two 70mm films exceeds 0.5 at all points, with the GSFC contact N-2 higher in MTF than the P-1 at all frequencies tested. This difference is caused by chemical edge enhancement in processing Kodak SO-467 film and probably disappears at frequencies slightly finer than those in Figure 4.

The curves made at Sioux Falls predict the observed limiting resolution of 9 to 13 lp/mm, while limiting resolution for the Kodak and GSFC prints at 18 to 25 lp/mm falls beyond the finest frequency in Figure 4. However, extrapolation of MTF curves for these prints leads to about the same threshold MTF (0.1 to 0.15) for 2.4:1 contrast resolution that was observed on the Sioux Falls prints.

Substantial improvement at Sioux Falls is shown by MTF curve 7A made after the Bessler enlarger was modified. This curve is now similar to those obtained at the other two laboratories. Adjustment of the Sioux Falls Bessler machine also removed a large difference (up to 0.3 in modulation) between the MTF curves measured on axis but perpendicular to each other. This effect is another indication of the need for critical and positive alignment between

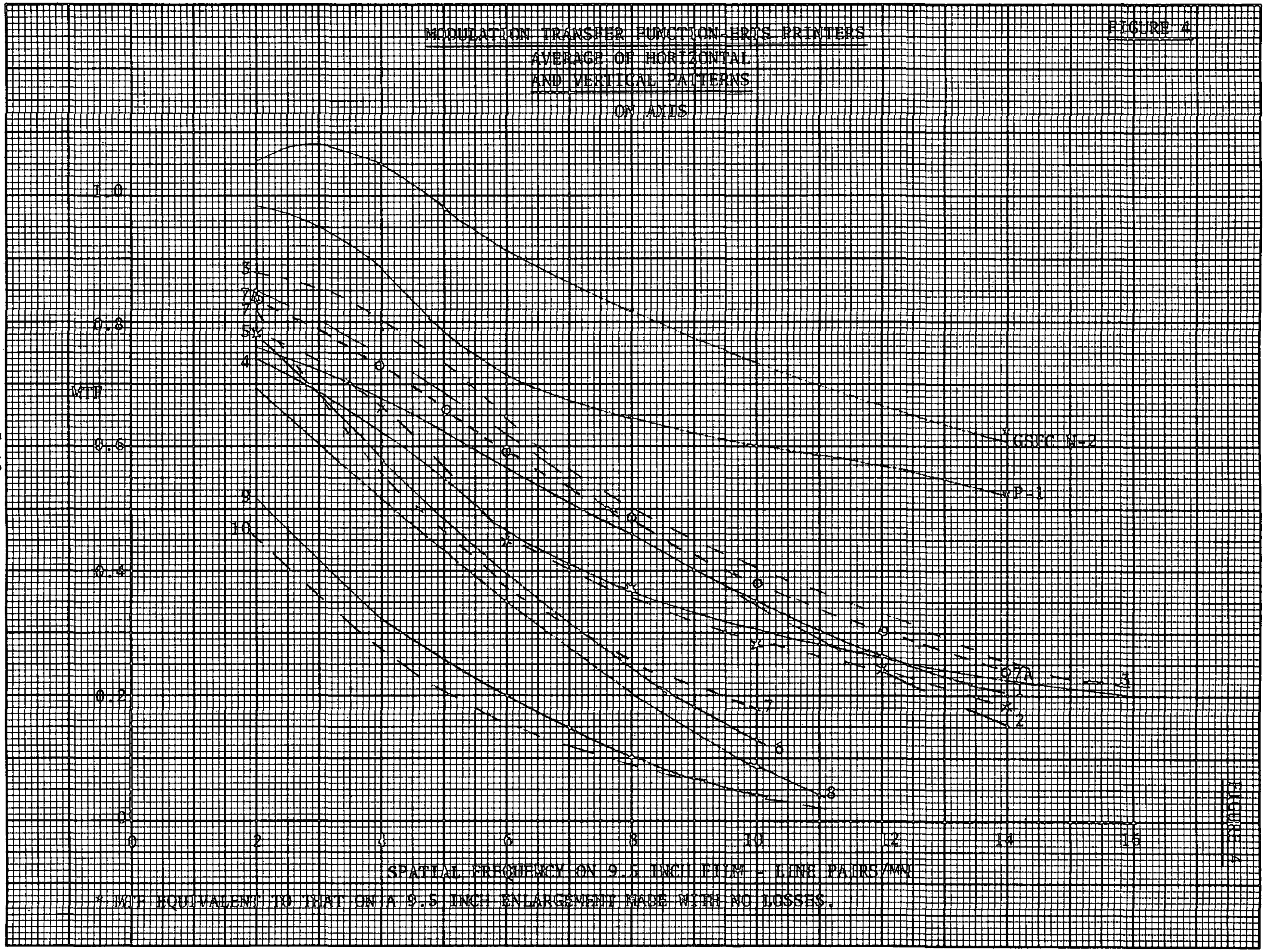


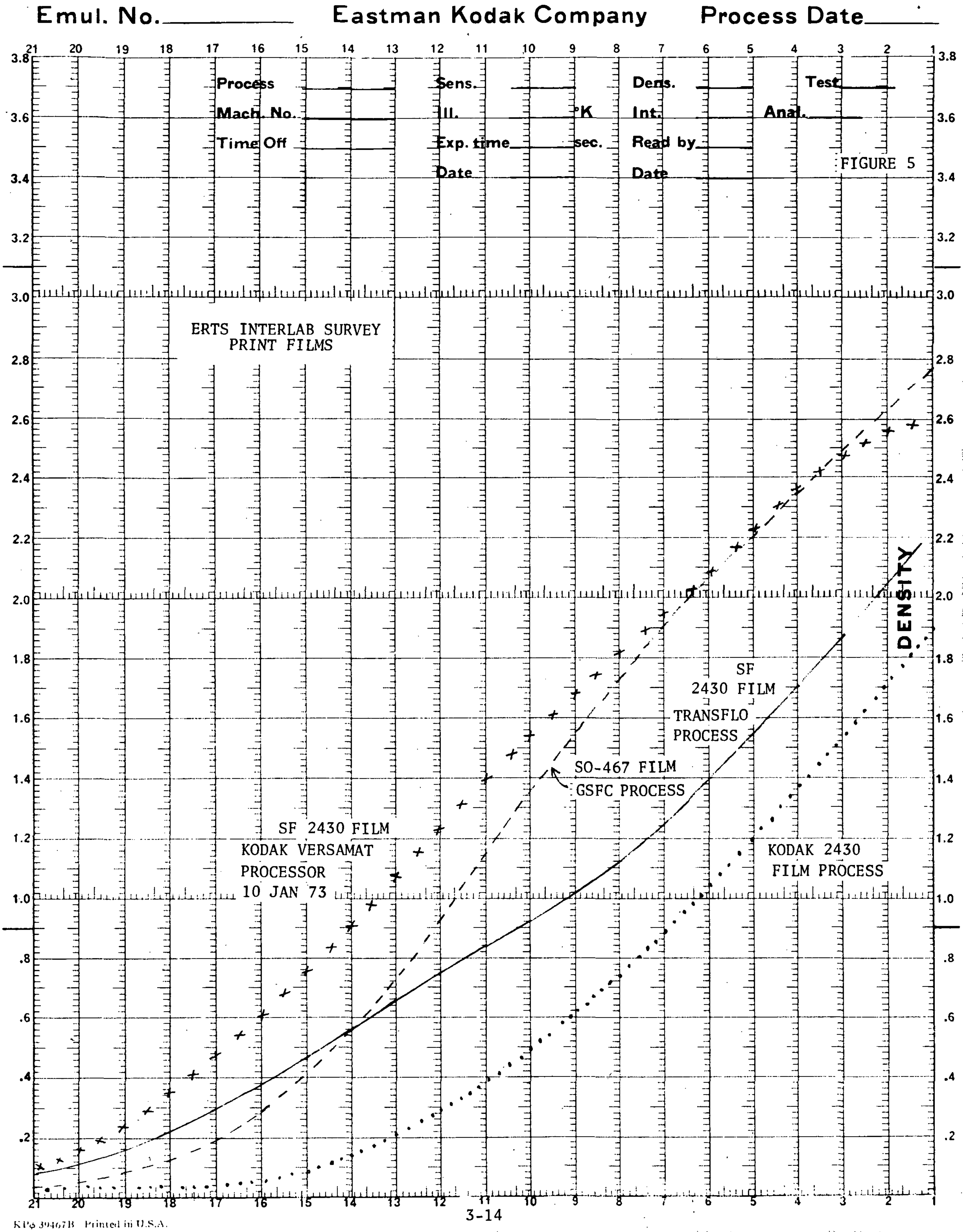
FIGURE 4
MODULATION TRANSFER FUNCTION-ERTS PRINTERS
AVERAGE OF HORIZONTAL
AND VERTICAL PATTERNS
ON AXIS
MTF
1.0
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
GSFC M-2
P-1
3
7A
7
5
4
9
10
7A
3
2
7
6
8
SPATIAL FREQUENCY ON 9.5 INCH FILM - LINE PAIRS/MM
* MTF EQUIVALENT TO THAT ON A 9.5 INCH ENLARGEMENT MADE WITH NO LOSSES.

enlarger lens and film planes in ERTS printing. Orthogonal MTF curves measured on Kodak and GSFC prints were nearly identical, indicating proper alignment of lens and film.

Tone Reproduction

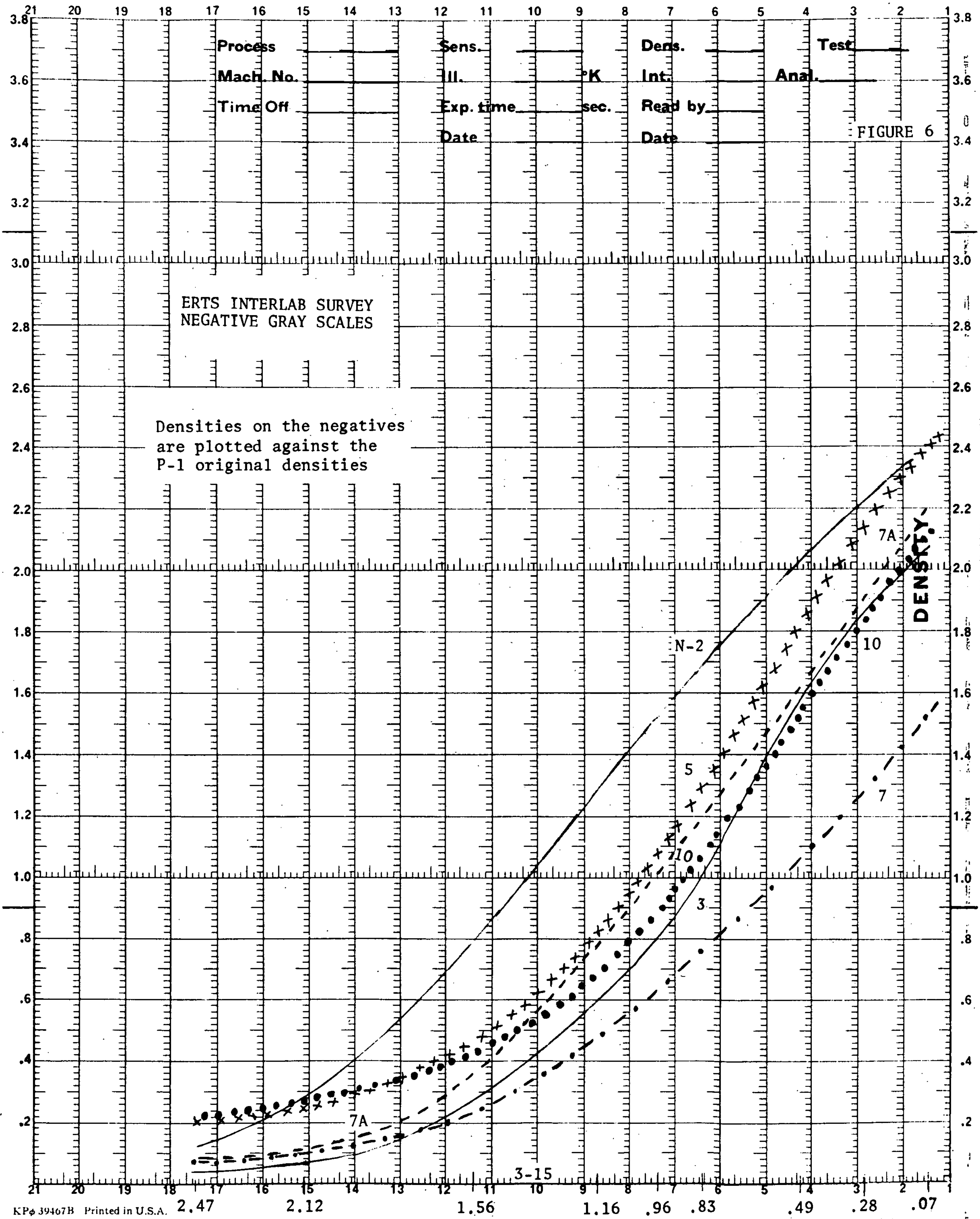
Print film characteristics curves exposed on each laboratory sensitometer and processed with the prints are shown in Figure 5. Here, the speed relationships are not correct but the relative gamma and curve shape are significant. Figure 6 shows print-through negative gray scales made from the 9 center test areas of the P-1. The most uniform scale - the N-2 contact print - reproduces P-1 densities from 0.07 to 2.47 in a nearly linear manner covering densities from 0.12 to 2.40. All optical negatives show tone distortion, especially at low P-1 densities, with the Sioux Falls print (7) having 0.7 less density range than the better prints. However, by using the Transflo curve in Figure 5 it can be shown that prints from the Bessler (7) and K&E (10) enlargers at Sioux Falls would be similar if negative (7) had been printed using 0.45 log E more exposure. Both enlargers have considerably more flare than that shown in the Kodak print (3).

In the second test at Sioux Falls, a much better optical print (7A) was produced. This curve has a density range equal to that produced by Kodak and GSFC and shows very linear tone reproduction, though not as good as on the contact-printed N-2.



Emul. No.
Eastman Kodak Company
Process Date
Process
Mach. No.
Time Off
Sens.
Ill.
°K
Exp. time
sec.
Date
Dens.
Int.
Read by
Date
Test
Anal.
FIGURE 5
ERTS INTERLAB SURVEY
PRINT FILMS
DENSITY
SF
2430 FILM
TRANSFLO
PROCESS
SO-467 FILM
GSFC PROCESS
SF 2430 FILM
KODAK VERSAMAT
PROCESSOR
10 JAN 73
KODAK 2430
FILM PROCESS
KP6 39467B Printed in U.S.A.

Emul. No. ______ Eastman Kodak Company Process Date ______



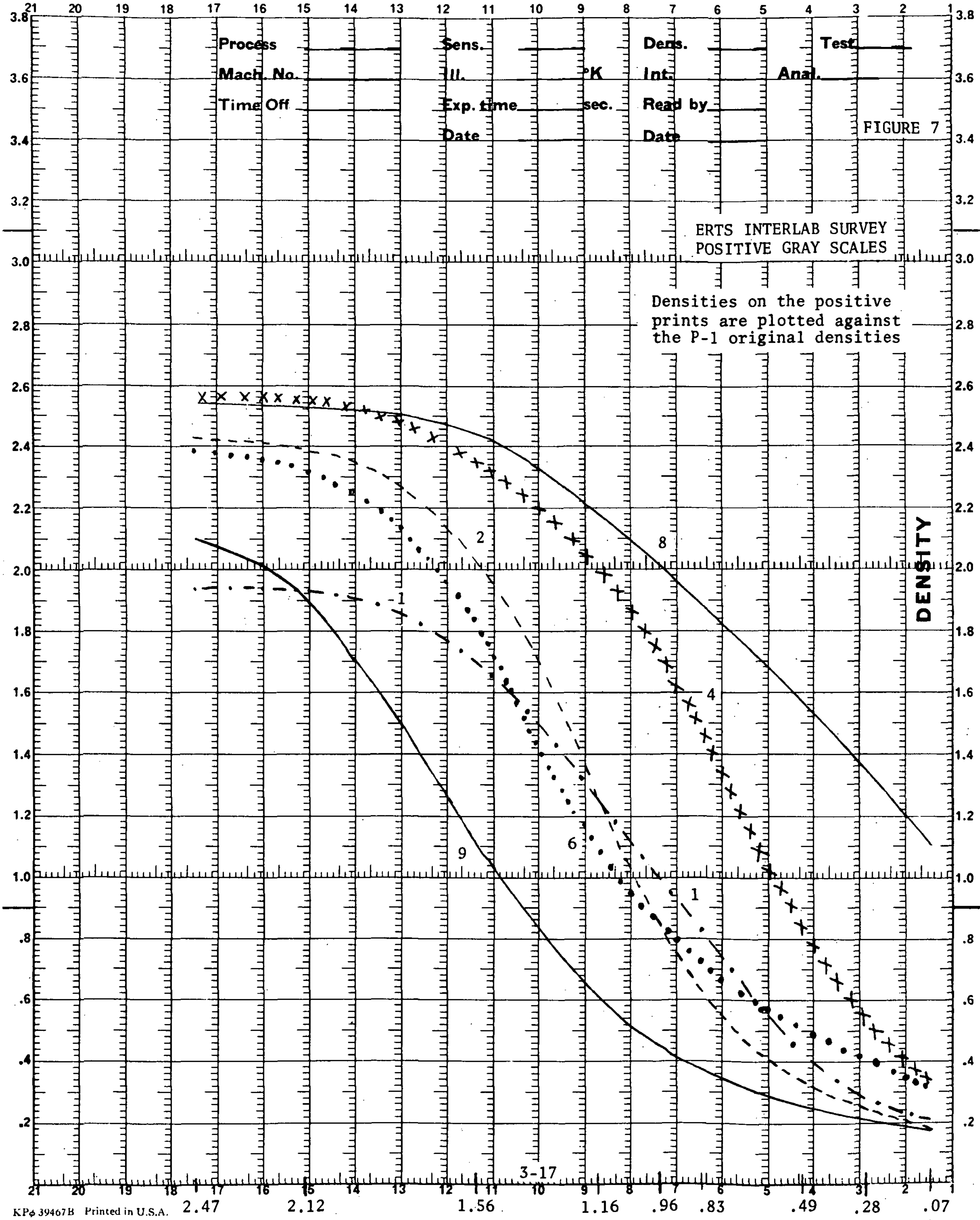
KPφ 39467B Printed in U.S.A.

Since the Kodak and GSFC negatives have about the same contrast in Figure 6, the enlarger at GSFC must have slightly more flare because the curve for SO-467 film in Figure 5 has higher gamma than the one for Kodak 2430 film.

Figure 7 shows overall tone reproduction curves for positive prints made in this test. Prints (1), (4), and (8) reflect the characteristics of previously enlarged negatives, while prints (2), (6), and (9) are made from the GSFC contact N-2. Print (8) from the Sioux Falls Bessler shows the expected compressed tone scale, and prints (6) and (9) also exhibit the effects of flare in the Sioux Falls equipment. Non linearity in the Transflo processor curve for 2430 film in Figure 6 also contributes to tone distortion in the Sioux Falls prints.

Of particular interest is the difference in contrast on Kodak prints (1) and (2). Print (1) has a gamma of 1.24 and was contact printed from a negative that was enlarged from the P-1. Print (2) is enlarged from the 70mm N-2 made by GSFC on SO-467 film; it has a gamma of 2.14. Since the printers and print film are identical for both prints, it is evident that the enlarger is "viewing" the N-2 on SO-467 film at much higher gamma than the P-1 on SO-438 film. If the N-2 made by GSFC is to be a true copy of the P-1 it should appear to have the same contrast by either optical or contact printing. Further study of the requirements for MTF, granularity, and tone reproduction on the 70mm N-2 may be needed to optimize the usefulness of this record in all kinds of printers. Possibly a special 70mm N-2 of finer grain and lower gamma may be necessary for those users who will make enlargements from this record.

Emul. No.________ Eastman Kodak Company Process Date______

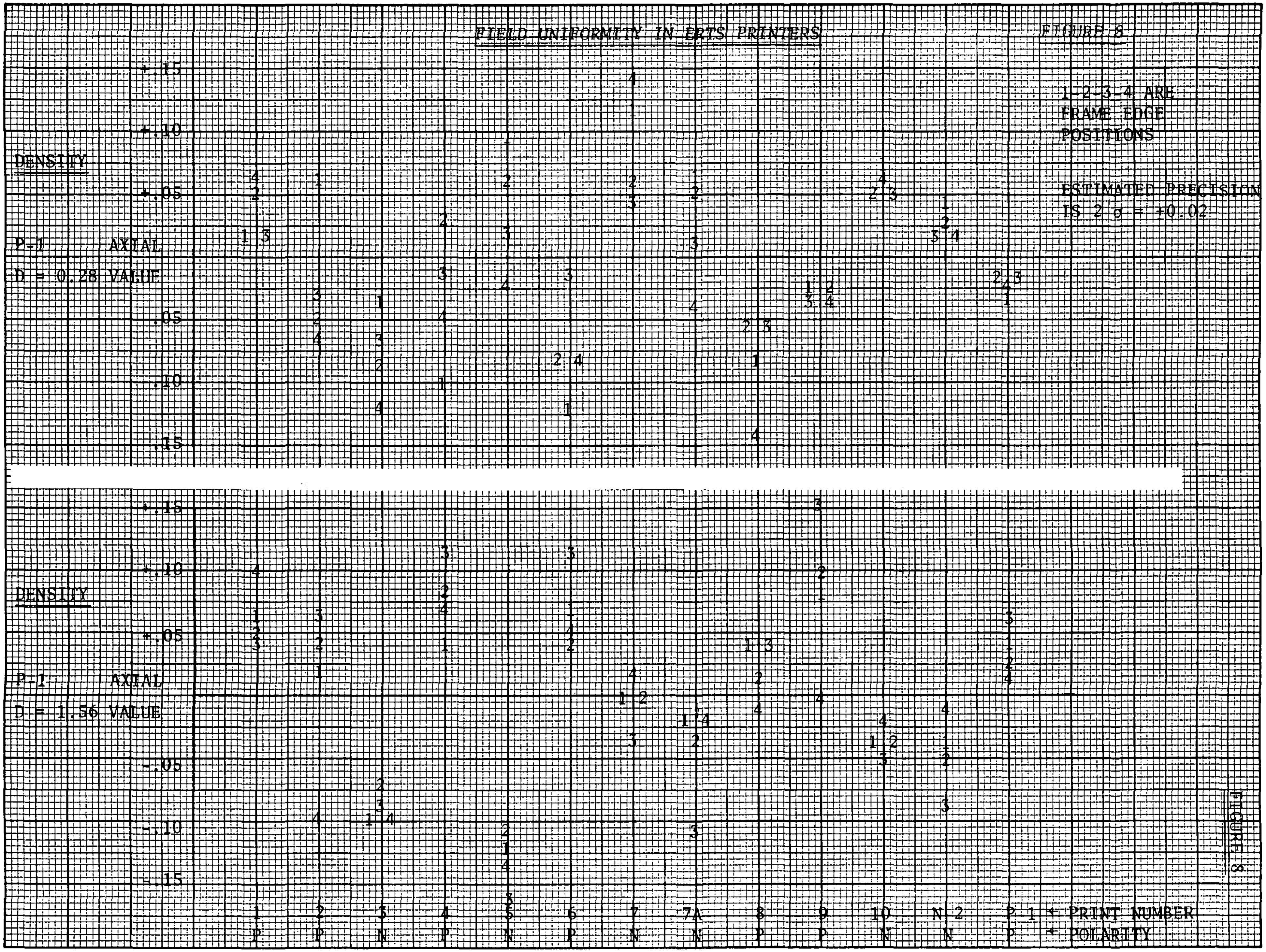


Another aspect of tone reproduction is the uniformity of tone rendition in all parts of the frame. This characteristic was checked by comparing the density of a light (D = 0.28) and a dark (D = 1.56) area near each edge of the P-1 test frame with the density of identical areas in the central gray scale. For both density levels, differences in the density between axis and edge are plotted in Figure 8. On this plot some edge areas deviate up to ±0.15 from the axial value, especially on prints (5), (7), and (9). Print (7A) shows some improvement in this respect over the first print (7) made on the Bessler enlarger at Sioux Falls.

Test areas at the edges and center of the original P-1 are uniform only to ±0.03 density, and this pattern is revealed and amplified in subsequent prints. Note that edge 3 at density 1.56 is high and remains that way on 5 of the 6 positive prints and is low on most negative prints. Also, at density 0.28 edge 1 is slightly low on the P-1 as it is on half of the positive prints; it is high on 5 out of 6 negative prints.

Absolute density values for the field areas are not shown in Figure 8 but are important. For instance, the apparent uniformity of print (9) at density 0.28 is caused in part by placement of the image near the toe of the characteristic curve; densities both on and off axis are compressed to a uniform value.

One point demonstrated by Figure 8 is the difficulty of precisely measuring apparent scene radiances by densitometry of a

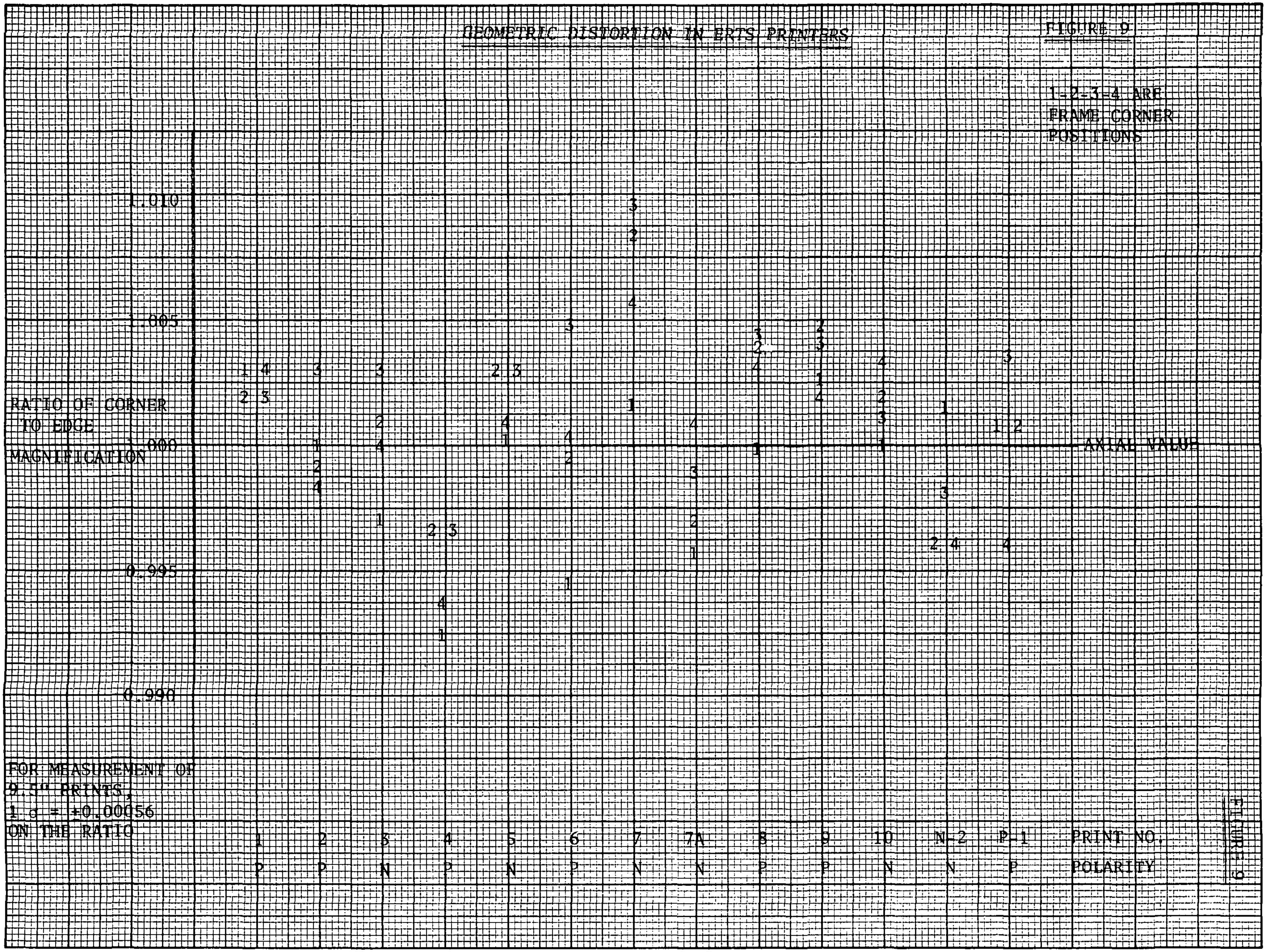

FIELD UNIFORMITY IN ERTS PRINTERS
FIGURE 8
1-2-3-4 ARE
FRAME EDGE
POSITIONS
ESTIMATED PRECISION
IS 2 σ = ±0.02
DENSITY
P-1 AXIAL
D = 0.28 VALUE
+.15
+.10
+.05
.05
.10
.15
DENSITY
P-1 AXIAL
D = 1.56 VALUE
+.15
+.10
+.05
-.05
-.10
-.15
1 2 3 4 5 6 7 7A 8 9 10 N-2 P-1 ← PRINT NUMBER
P P N P N P N N P P N N P ← POLARITY
FIGURE 8

photographic print. To the expected errors in densitometry, processing and system parameters must be added the uncertainty from nonuniform printing revealed in Figure 8. At low densities, this last factor can introduce errors of up to ±50% in some prints.

Geometric Distortion

A measurement was made of the difference in magnification between each corner and the center of the frame. This ratio is plotted in Figure 9 for each enlargement and for the 70mm P-1 original and the N-2 made at GSFC. These data were obtained by measuring the length of the complete tribar array in each of the five positions. The length in each corner was then compared to that in the center to obtain the ratios plotted in Figure 9.

All areas on most of the prints show magnification ratios within ±0.005 of unity. The Bessler enlarger at Sioux Falls, print (7), showed up to 1% distortion, but this was reduced later (7A) by proper alignment of lens and film. It is not clear why print (4) made on the Kodak Colorado printer at GSFC should show poorer geometric properties than print (5) from which it was made. Distortion of prints made on the Colorado machine is usually ±0.03% or less. Properly designed and adjusted optical or contact printers probably do not show a serious amount of distortion compared to that caused by other parts of the ERTS imaging system.

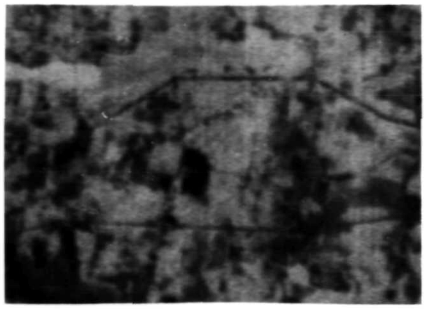

GEOMETRIC DISTORTION IN ERTS PRINTERS
FIGURE 9
1-2-3-4 ARE
FRAME CORNER
POSITIONS
RATIO OF CORNER
TO EDGE
MAGNIFICATION
1.010
1.005
1.000
0.995
0.990
AXIAL VALUE
FOR MEASUREMENT OF
9.5" PRINTS,
1 σ = ±0.00056
ON THE RATIO
PRINT NO.
1 2 3 4 5 6 7 7A 8 9 10 N-2 P-1
POLARITY
P P N P N P N N P P N N P
FIGURE 9

Picture Test

The enlargements in Figure 10 are made from part of the Seattle test frame (RBV No. 2) to illustrate the practical effect of the photographic and optical differences previously discussed. All are 5X enlargements from 9.5-inch prints except those labeled "GSF N-2" and "Original P-1" which are enlarged 16.8 times from the 70mm film. The six negative pictures at the top of Figure 10 were made by laboratories in this survey directly from the 70mm P-1 scene. Positive prints on the lower half of the page are made from 70mm or 9.5-inch N-2's and may be compared to the original P-1 image near the center of Figure 10. All scenes were enlarged onto KODAK Low Contrast Fine Grain Aerographic Duplicating Film (ESTAR Base) SO-355 which was then contact printed onto Kodabromide paper without dodging or other adjustment.

Individual EBR scan lines are reproduced in the GSFC contact N-2 and in enlargements (1), (3), (4), and (7A). Prints from the first test at Sioux Falls are soft and low in contrast, but a dramatic improvement is seen in the second test (7A). Careful comparison of prints (1) and (2) shows (1) to be sharper although much lower in contrast.

Prints made directly from the P-1 original [(3), (5), and (7A)] show more detail than those made from the GSFC N-2 [(2), (6), and (9)]. This difference is more pronounced in these scenes taken half way to the edge of the frame than it would be on axis, as the 3.369X optical printer at GSFC shows significant loss in resolution off axis.



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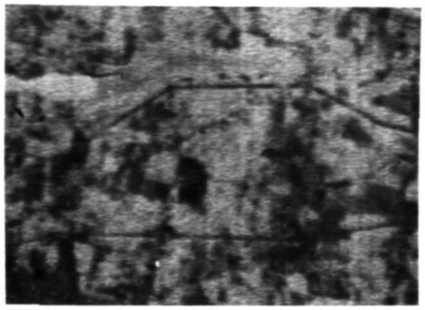
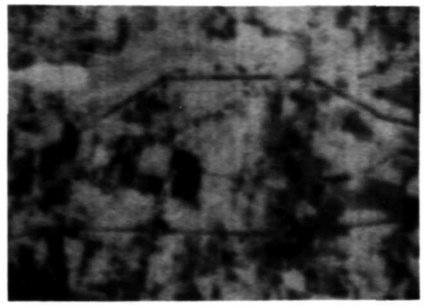
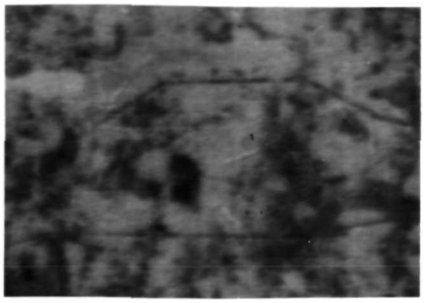


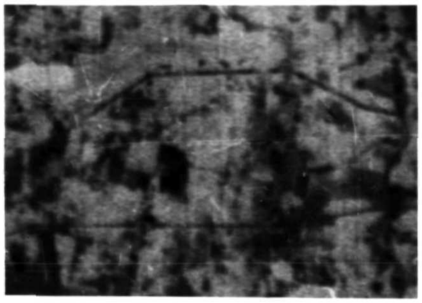
GSFC N-2



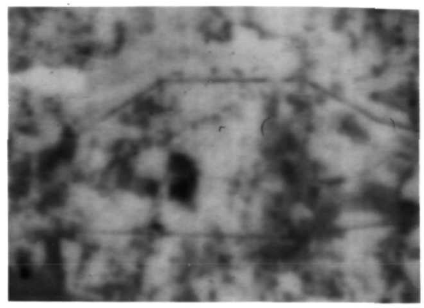
5



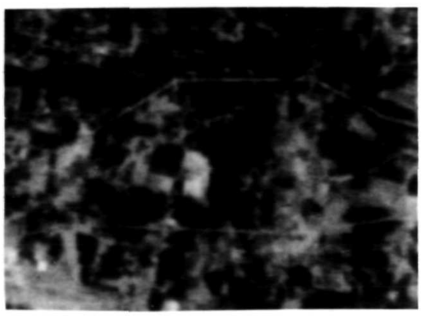
7



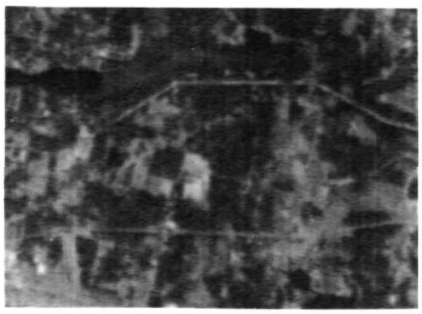
7A



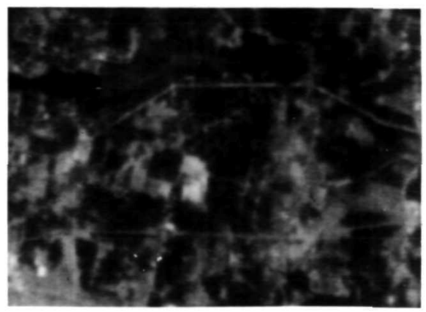
10



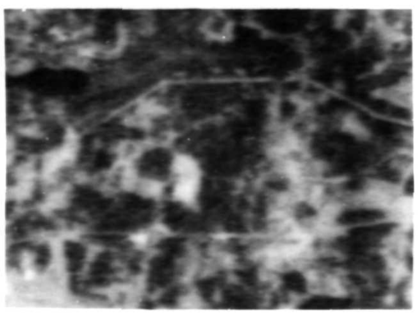
2



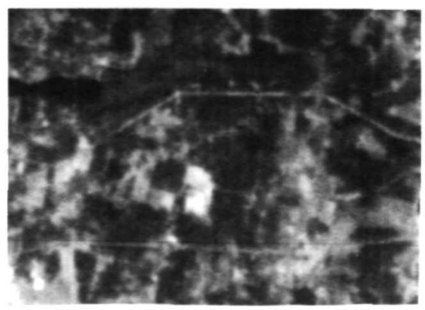
ORIGINAL P-1



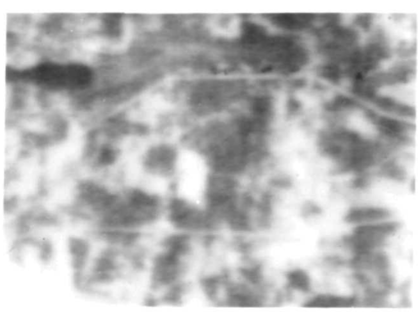
1



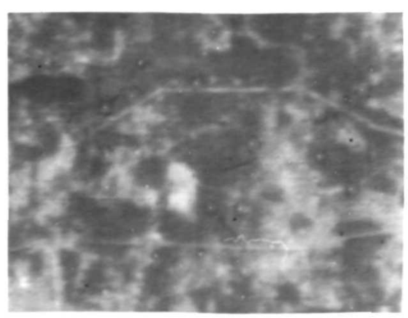
6



4



9



8

FIGURE 10

ENLARGEMENTS FROM AREA IN SEATTLE TEST SCENE LOCATED HALF WAY TO EDGE OF FRAME. P-1 AND N-2 ENLARGED 16.8X; ALL 9.5 INCH PRINTS ENLARGED 5X. CONTRAST AND INTENSITY REPRODUCTION IS UNIFORM FOR ALL PRINTS.

Recommendations

The following action is suggested based on the results of this survey:

(1) Maintain the gain in image quality obtained at Sioux Falls by providing positive adjustments to position the lens and condensers relative to the lamp and the film. Purchase and install a better enlarger lens.

(2) Study the 3.369X enlarger at GSFC to improve the off axis performance.

(3) Adjust the Kodak Colorado printer at GSFC to produce uniform quality across the 70mm N-2 print. Run tests to demonstrate any useful gain from using 2430 film in place of SO-467 film for this N-2 contact print.

(4) At each laboratory, study the uniformity of illumination in optical prints and make masks or other adjustments to improve the reliability of radiometric measurements made on the enlargements.

(5) Try to remove sources of flare light in the enlargers. Potential causes of flare are dirty optics, improper match of condensers to objective lens, and poorly blackened or unbaffled scattering surfaces between the light source and the unexposed film.

(6) In view of the use of the 70mm N-2 for optical printing at Sioux Falls, reassess the requirements for sharpness, granularity, tone reproduction and printing contrast in a 70mm N-2 made for this purpose.

(7) Run a daily or weekly check on the photographic output of printers at the Sioux Falls and GSFC laboratories. Set useful standards and devise critical test frames for this check. Low contrast tribar resolution and illumination uniformity are important items that may be measured rather quickly.

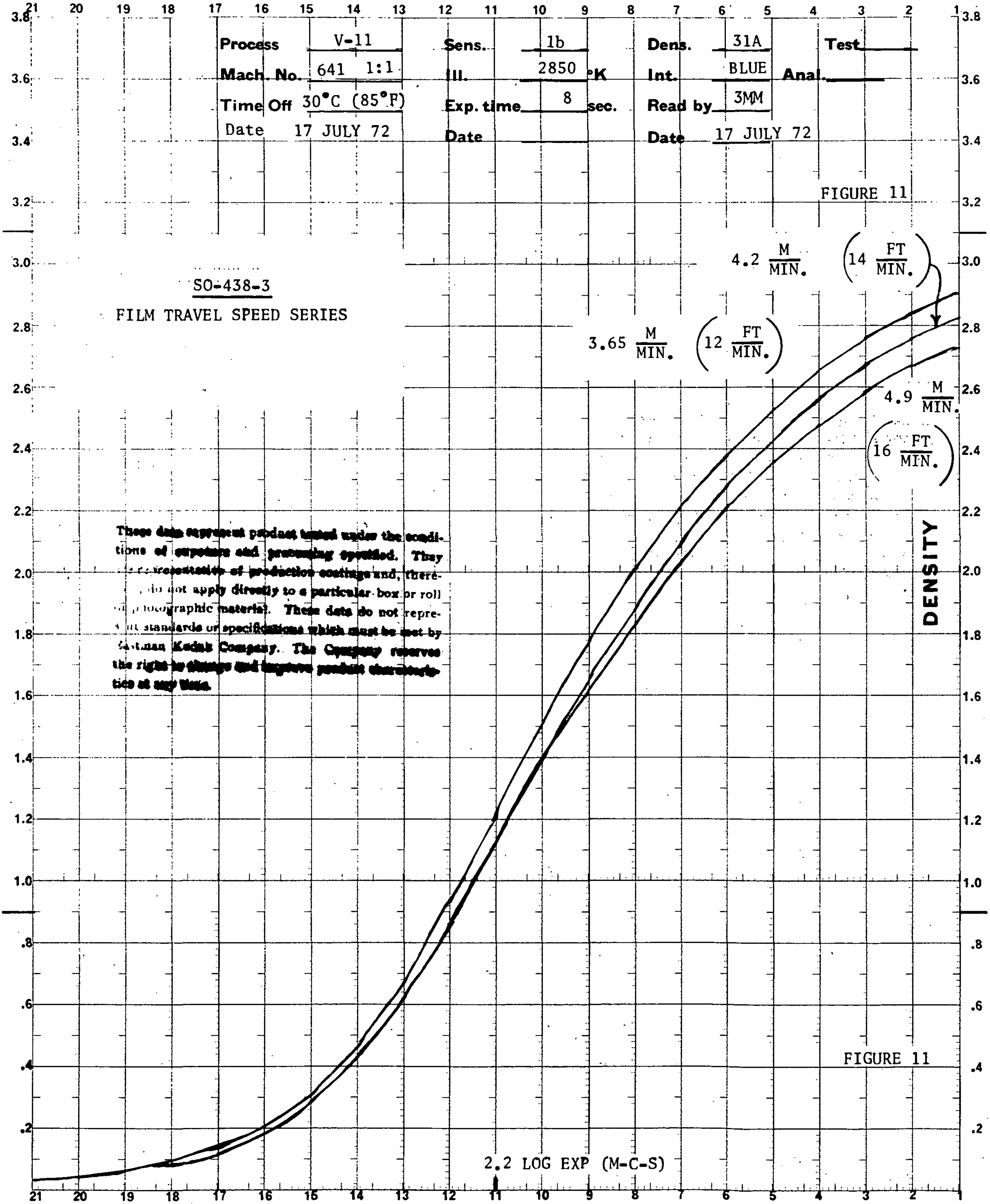
Processing of EBR Film

To insure proper radiometry and tone reproduction, NASA is striving for very low variability in the primary film record produced by the Electron Beam Recorder. This device exposes Eastman Electron Recording Film (ESTAR Base) SO-438 for subsequent treatment in the Kodak Versamat Processor Model 11. Kodak MX-641 Chemicals, diluted 1:1 are used in this processor to obtain the desired sensitometry in a reasonable development time.

The purpose of this work was to measure the variability of SO-438 film and processing in order to determine realistic operating tolerances for this recording system. Twelve rolls (70mm x 46 meters (150 feet)) of SO-438 film were obtained from stock similar to that used to fill orders for NASA-GSFC. Tests were made for film uniformity along and across the factory coated roll, for density variability during processing of 365 meters of film in 13 days, for densitometer variability, and for the effect of latent image keeping. Additional runs were made to learn the effect of changes in film travel speed and in developer temperature.

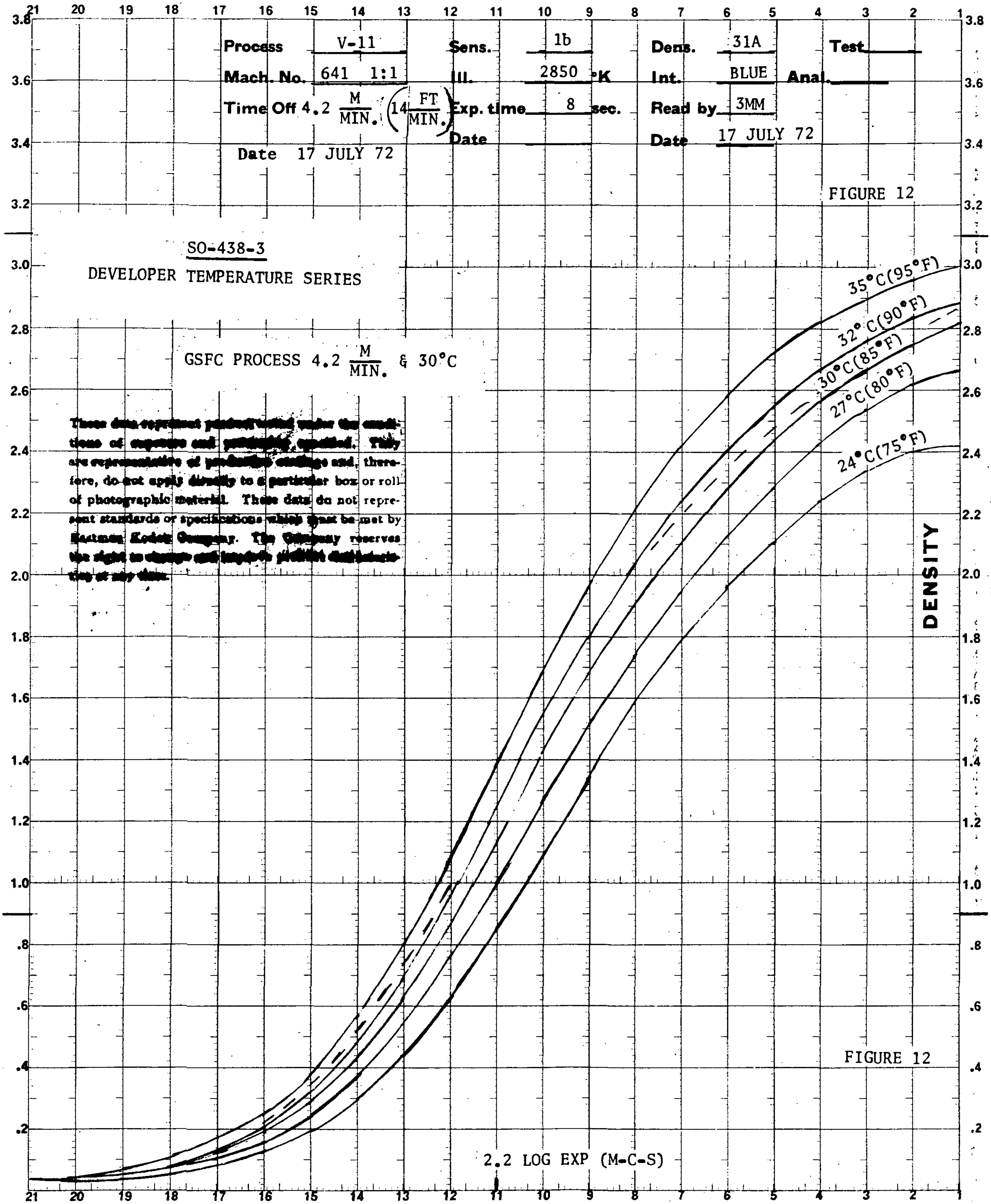
Figures 11 and 12 show that a change in development time (film travel speed) moves the D-log E curve very little while variations of 3°C in developer temperature have a significant effect. The dashed curve from the GSFC process is well matched

Emul. No.________ **Eastman Kodak Company** Process Date________



Pφ 39467B Printed in U.S.A.

Emul. No.__________ Eastman Kodak Company Process Date______



KPφ 39467B Printed in U.S.A.

by our run made under the same process settings. Exposure time is 8 seconds on the Kodak 1b sensitometer compared to 5 seconds on the GSFC Herrnfeld sensitometer.

Variability in the combination of SO-438 film and Kodak 1b sensitometer was measured by exposing two gray scales on strips from the head end of 11 rolls of film and similar scales at the middle and tail end of one 70mm roll. All strips were processed at one time and densities read on the Eastman Electronic Densitometer Model 31A using a 3mm aperture and a Kodak Status A blue filter. A density near 1.0 appears most sensitive to changes in film and processing and was selected for a statistical measure of film-sensitometer variability. The one sigma variation in density was ±0.03 along the roll and ±0.05 across the 11 rolls.

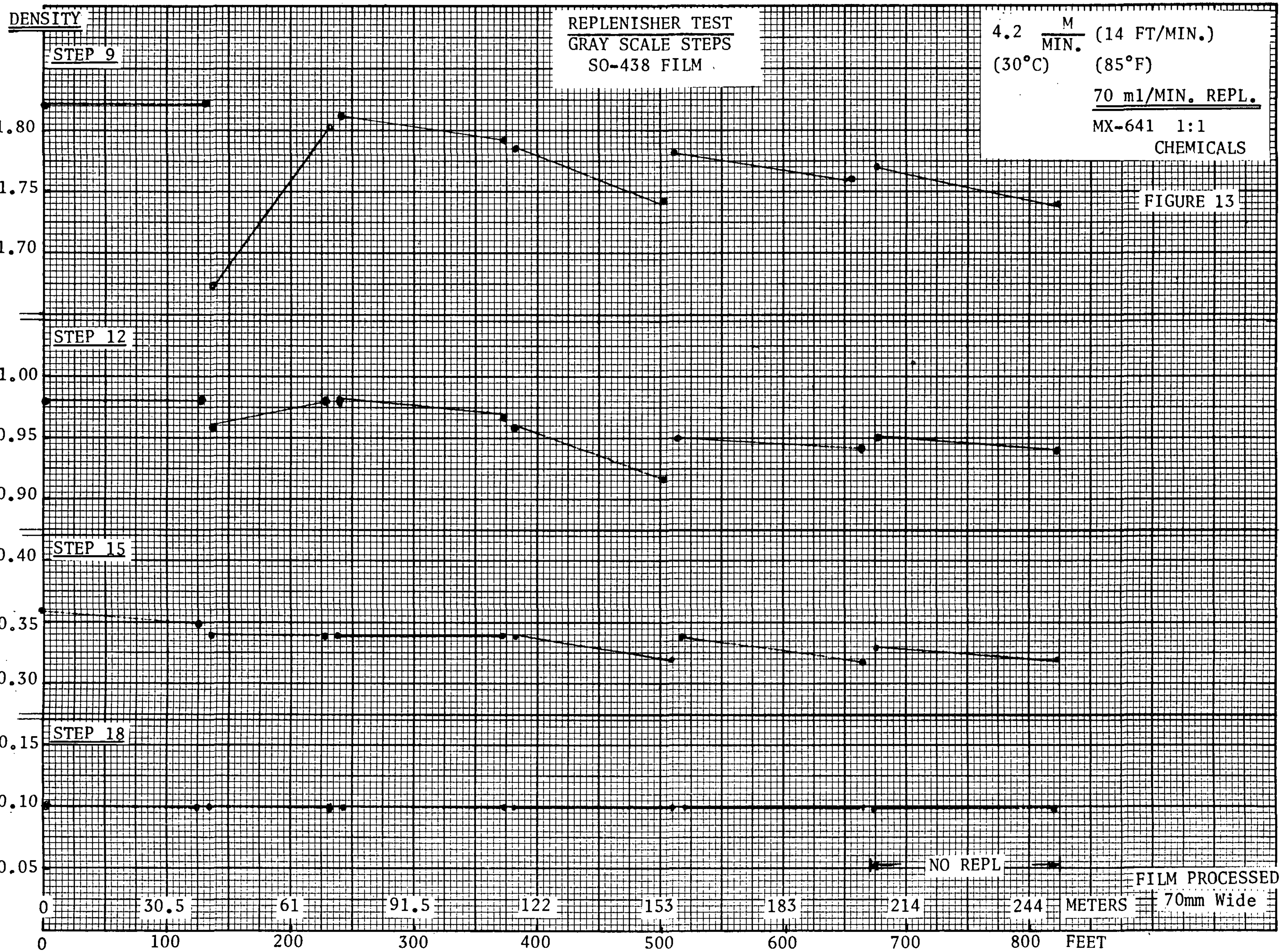
A similar one sigma value of ±0.006 was determined for the densitometer by reading the same gray scale 11 times in 10 days. Further tests revealed that sensitometry is not changed by processing gray scales with either the heavy or light exposure end first through the Kodak Versamat machine.

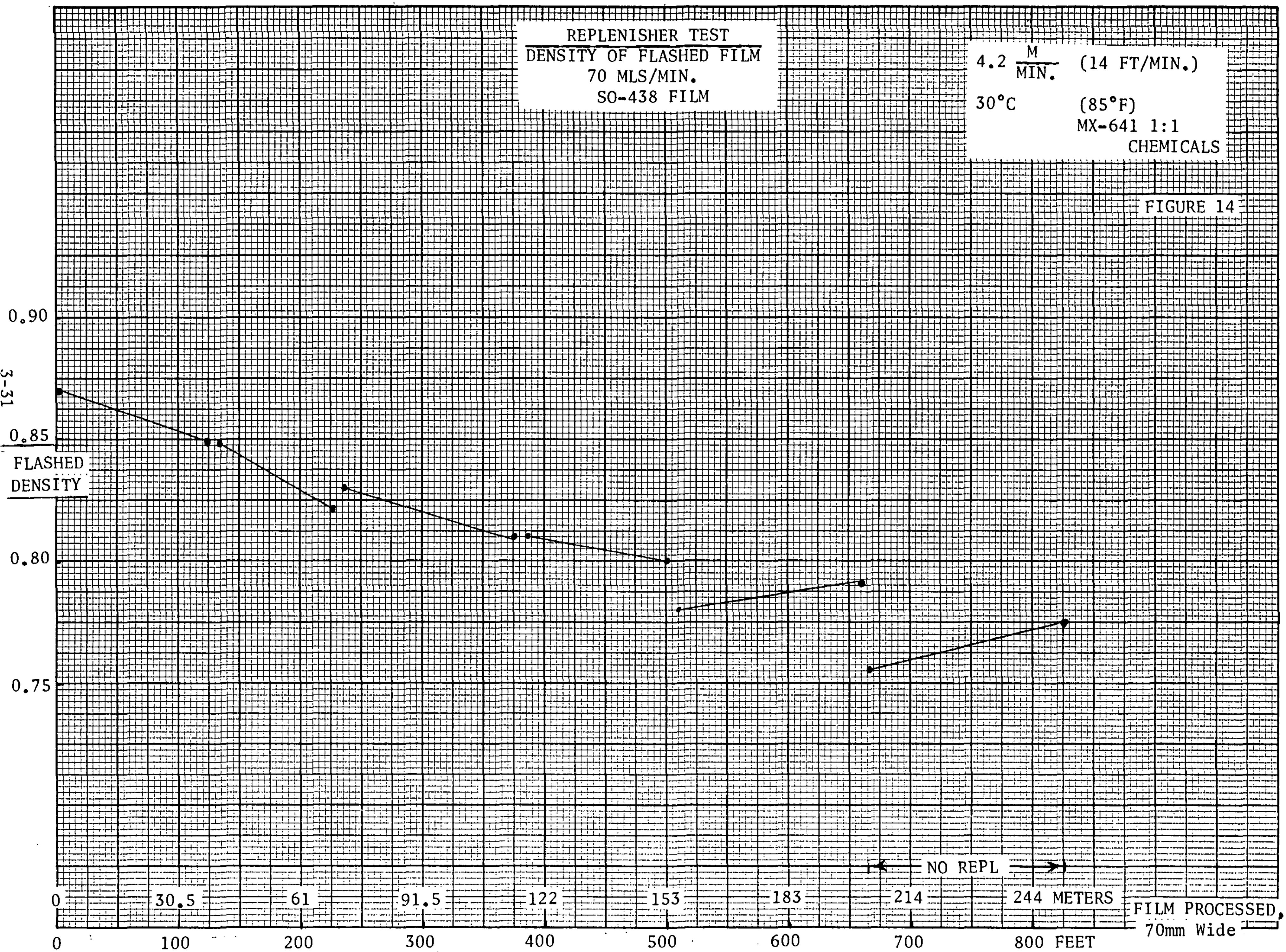
Extensive testing is required to properly study the overall variation in process control strips. Our tests were limited to processing 365 meters of 70mm film at two replenisher

rates over a period of 13 days. Each roll of SO-438 film was flashed on a precision printer to a density of about 0.85 and was accompanied through the process by gray scales at the head and tail of the roll. All gray scale strips were cut from a single roll of film, randomized, exposed on the Kodak 1b sensitometer, and frozen prior to use.

Densities from four gray scale steps processed with the first 244 meters of film are shown in Figure 13. A developer replenishment rate of 70 mls/min. was used for all but the final run when no replenisher was used. Under replenishment is indicated in Figure 13 by a small loss in density with increasing footage (especially for Step 12, D = 0.95), but this effect is more apparent in Figure 14 which shows the loss in density on the flashed film.

The final three rolls of film were processed with a developer replenisher rate of 100 mls/min. and produced the nearly constant densities shown in Figure 15. Although these data are very limited evidence on which to base a replenisher rate or to determine process control limits, it does appear that 100 mls/min. is a useful replenisher rate. Statistical analysis of the density variation for Step 12 in both replenisher runs yields a one sigma value of ±0.02 after removal of the overall density loss at 70 mls/min.


DENSITY
REPLENISHER TEST
GRAY SCALE STEPS
SO-438 FILM
4.2 M/MIN. (14 FT/MIN.)
(30°C) (85°F)
70 ml/MIN. REPL.
MX-641 1:1
CHEMICALS
STEP 9
1.80
1.75
1.70
STEP 12
1.00
0.95
0.90
STEP 15
0.40
0.35
0.30
STEP 18
0.15
0.10
0.05
NO REPL
FILM PROCESSED,
70mm Wide
0
30.5
61
91.5
122
153
183
214
244
METERS
0
100
200
300
400
500
600
700
800
FEET
FIGURE 13


REPLENISHER TEST
DENSITY OF FLASHED FILM
70 MLS/MIN.
SO-438 FILM
4.2 M/MIN. (14 FT/MIN.)
30°C (85°F)
MX-641 1:1
CHEMICALS
FIGURE 14
0.90
0.85
FLASHED
DENSITY
0.80
0.75
NO REPL
0
30.5
61
91.5
122
153
183
214
244 METERS
FILM PROCESSED,
70mm Wide
0
100
200
300
400
500
600
700
800 FEET

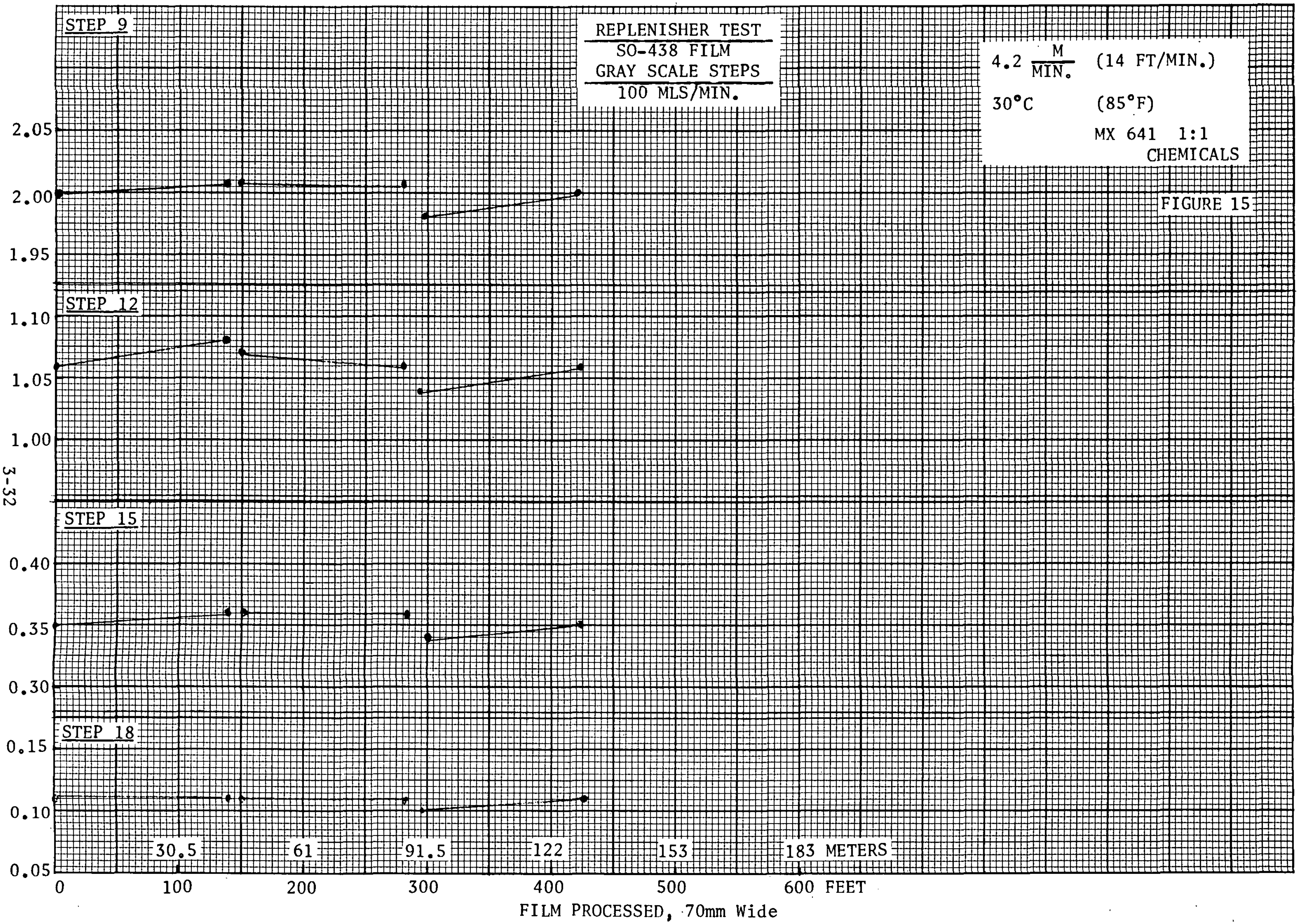

REPLENISHER TEST
SO-438 FILM
GRAY SCALE STEPS
100 MLS/MIN.
4.2 M/MIN. (14 FT/MIN.)
30°C (85°F)
MX 641 1:1
CHEMICALS
STEP 9
2.05
2.00
1.95
STEP 12
1.10
1.05
1.00
STEP 15
0.40
0.35
0.30
STEP 18
0.15
0.10
0.05
30.5
61
91.5
122
153
183 METERS
0
100
200
300
400
500
600 FEET
FILM PROCESSED, 70mm Wide

FIGURE 15

The preceding variability factors are summarized in Table II where it appears the contribution from film plus sensitometer is 3 times greater than the overall variance. However, the process control value of ±0.02 will increase as the sample size increases, and may approach the ±0.05 for Across Roll variability as the number a gray scales becomes very large. An overall one sigma limit of ±0.04 at density 1.0 seems reasonable for a series of control strips cut from one roll. This value agrees fairly well with experience on the process at GSFC.

Table II also describes the 0.10 loss in density (at D = 1.0) caused by latent image keeping for 1 to 2 days at 23°C. In this test three gray scales were exposed for each condition on randomized strips of SO-438 film using the Kodak Model 60 Sensitometer. Strips were stored at either -18° or 23°C for 6 to 48 hours after exposure, then were all processed together in the Kodak Versamat processor at 30°C and 4.2 meters/minute.

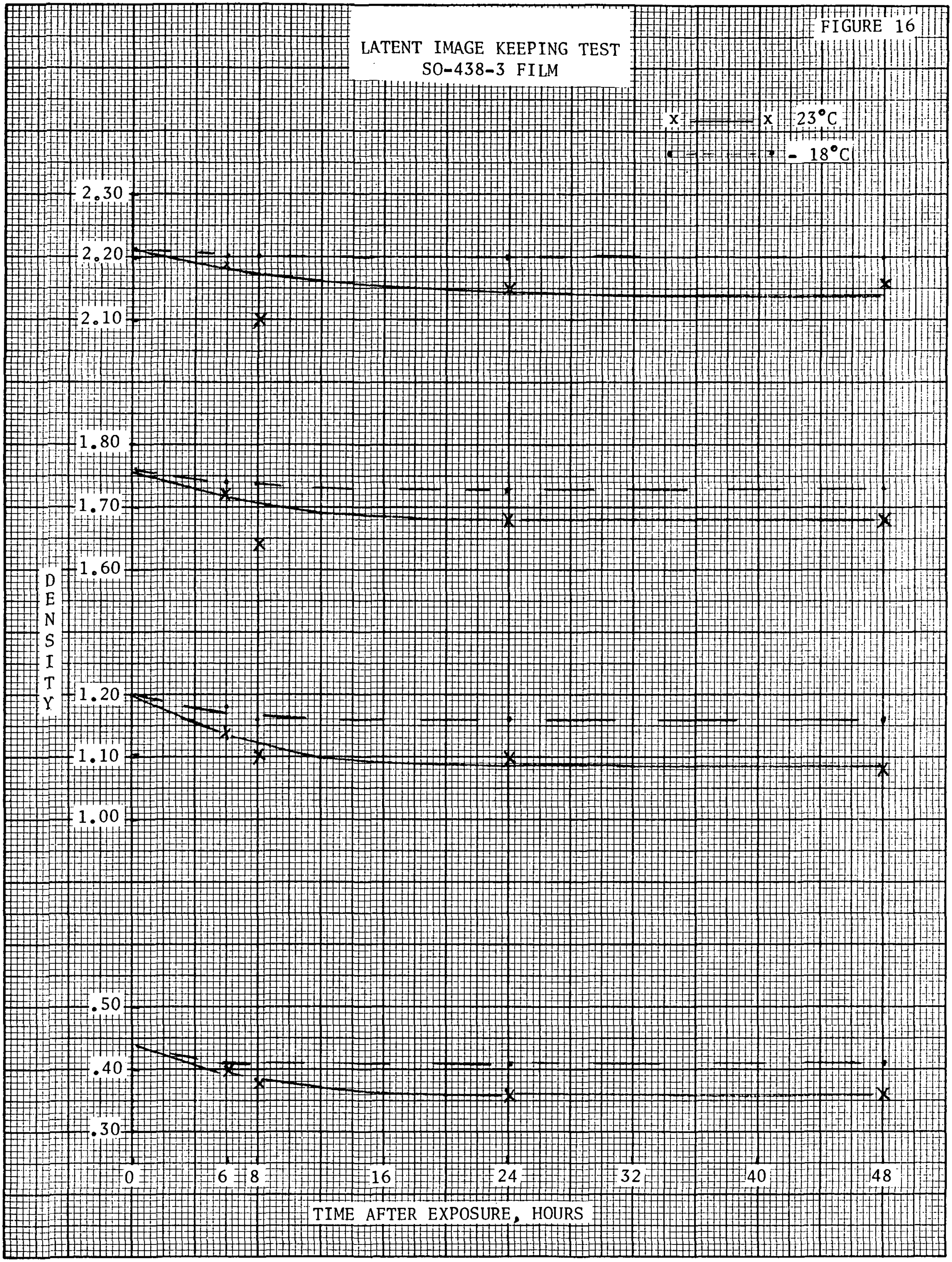
Densities from the 3 strips were averaged for each test condition and are plotted in Figure 16 for 4 of the gray scale steps. Even at -18°C some of the image is lost 8 hours after exposure, but the effect is 3 times greater at 23°C. Since latent images losses at room temperature seem to level out after 24 hours, it is suggested that control strips be kept at 20°C for 1 or 2 days after exposure and prior to freezing to allow this aging effect to occur.

Table II

Variability Tests on Kodak
SO-438 Film

		±1 Sigma at Density $\cong$ 1.0
Kodak 1b Sensitometer + SO-438 Film	- Along Roll	0.03
	- Across Roll	0.05
Kodak 31A Densitometer		0.006
Head First or Tail First on Kodak Versamat Processor		0.00
Overall Process Control 18 samples 365 meters (1200 feet) 1b control strips cut from single roll		0.02

Effect of latent image keeping 1 to 2 days at 23°C (73°F)	Density loss = 0.10



10 X 10 TO THE ½ INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.

Measurement of Distortion on the Colorado Printer

As an aid in locating sources of geometric distortion in ERTS photographs, we evaluated the distortion caused by printing an original SO-438 film onto KODAK Aerial Duplicating Film (ESTAR Base) SO-467 using the GSFC Colorado printer. Distortion is determined by measuring the moirè pattern formed when an original and the print are compared to a glass plate master for a repetitive pattern image.

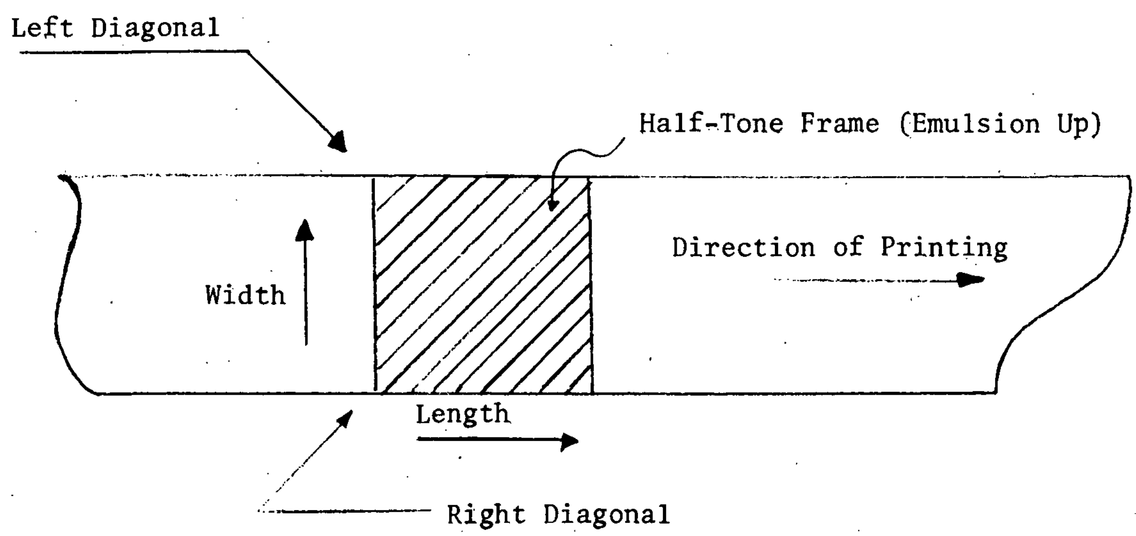
A half tone screen of 40 lines/mm was carefully printed onto 70mm SO-438 film in five 70mm square areas spaced at equal intervals in a roll of 36.5 meters. After tests run in Rochester to verify the quality of this original film pattern, the roll was printed onto SO-467 film using the Kodak Colorado printer at the ERTS Photographic Laboratory. Both the original SO-468 film and the SO-467 print film are superimposed on a second glass master having a line frequency that is slightly different from that on the original glass screen. The line patterns on the glass master and the film image interact to produce a moirè pattern that is measured for frequency and uniformity. Comparison of the patterns made by the original film and the print film yields a measure of the distortion caused by exposing and processing the print film.

The results of this test are summarized below where Test Area #1 was printed first on the roll. All film was on standard 5.4 cm diameter "A" cores.

Distortion Expressed as Percent Change in Size

Test Area	Length	Width	L Diag.	R Diag.
1	-0.028	+0.017	0.014	-0.072
2	-0.037	+0.017	0.007	-0.017
3	-0.035	+0.012	0.013	-0.034
4	-0.031	+0.016	0.011	-0.021
5	-0.031	+0.015	0.009	-0.024

The orientation of the above four directions is depicted by the following diagram.



The Colorado Printer reduces the length of the frame while slightly increasing the width. The length reduction is caused by the wrapping the original over the duplicating film which in turn is wrapped over a drum. For every revolution of the drum, slightly less duplicating film than original material will pass the printing aperture.

The difference in diagonal distortion values indicates that square frames take on a parallelogram shape. This change is caused by rollers that are not in perfect alignment with the film.

While the negative values for length distortion could be decreased by increasing tension in the original strand, this would tend to accentuate the diagonal distortion differences.

It is concluded that the best tension balance for distortion occurs at or near the recommended tension settings for the film combinations tested. The tensions for this test were measured and appear below:

FILM TENSION ON KODAK
COLORADO PRINTER

Supply Spindles

Tension Setting	Tension Range
45	2.3 - 3.8 kgms (5.12 - 8.35 lb.)

Take-Up Spindles

Tension Setting	Tension Range
65	0.4 - 1.2 kgms (1.62 - 2.68 lb.)

The variation in tension is caused by changes in spool diameters as the material passes from the supply to the take-up spindles. This variation does not significantly affect the distortion values from the test film materials.

Filter Curves

During our work on the Colorado Printer, personnel at the NDPF requested transmission curves for the filters in this machine. These data are given in Figure 17.

Microdensitometer Service

Early in our association with the ERTS program, Mr. A. Shulman requested that we read on a Kodak microdensitometer a number of test patterns generated in the ERTS printing cycles. This request stemmed from the need to improve on the speed of such service received when previous material had been sent to a laboratory at Los Alamos, N. M. Data were needed on granularity, modulation transfer function, and edge sharpness for several printing stages. Multiple film samples for each stage were exposed and measured to increase confidence in the data.

On 16 June J. Polger of the General Electric Co. staff at GSFC delivered to Kodak in Rochester processed film samples containing uniform gray patches for granularity measurement and sine wave images for determination of MTF. The sequence of laboratory operations used to generate the MTF test material is outlined in Table III.

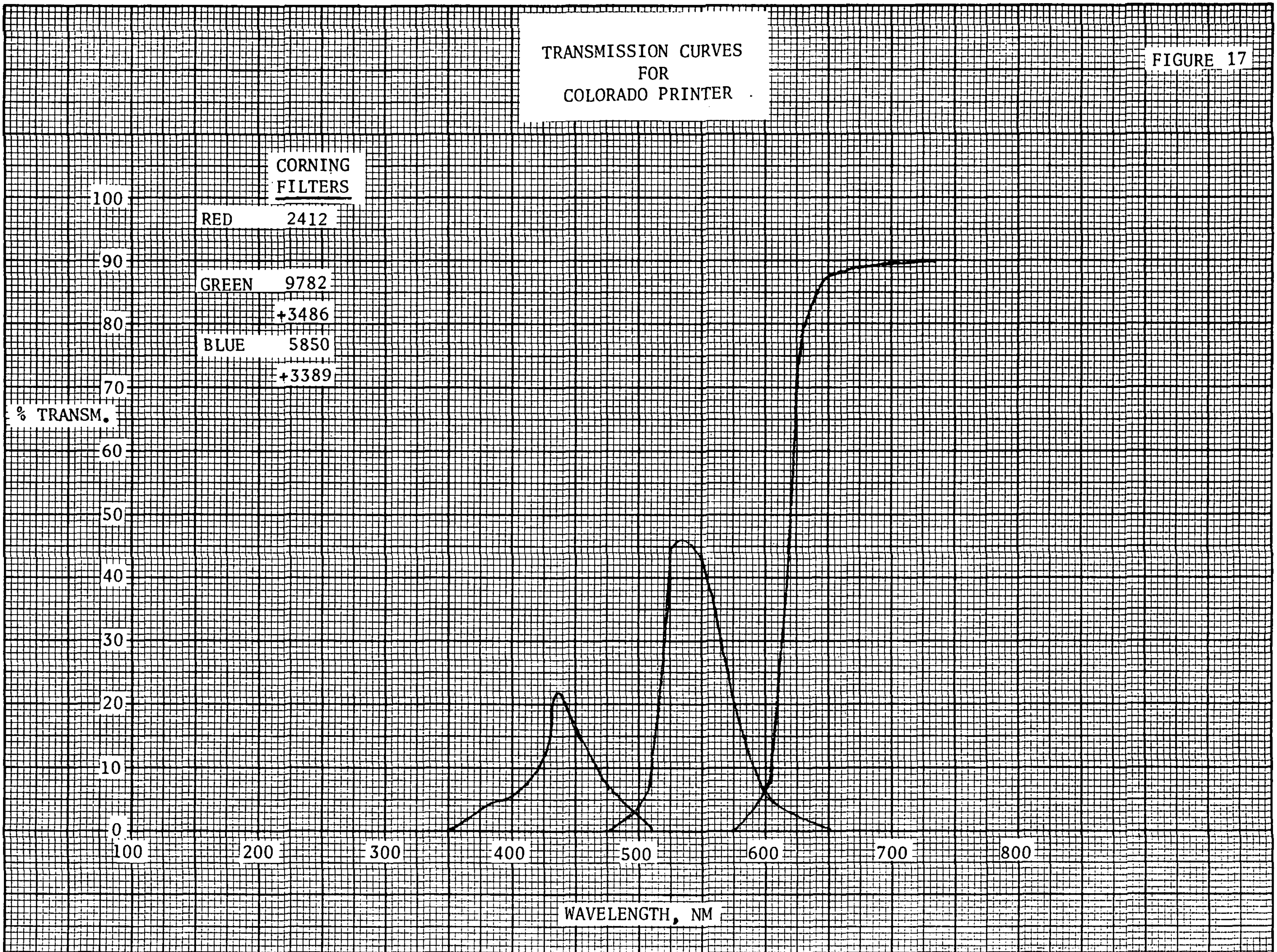
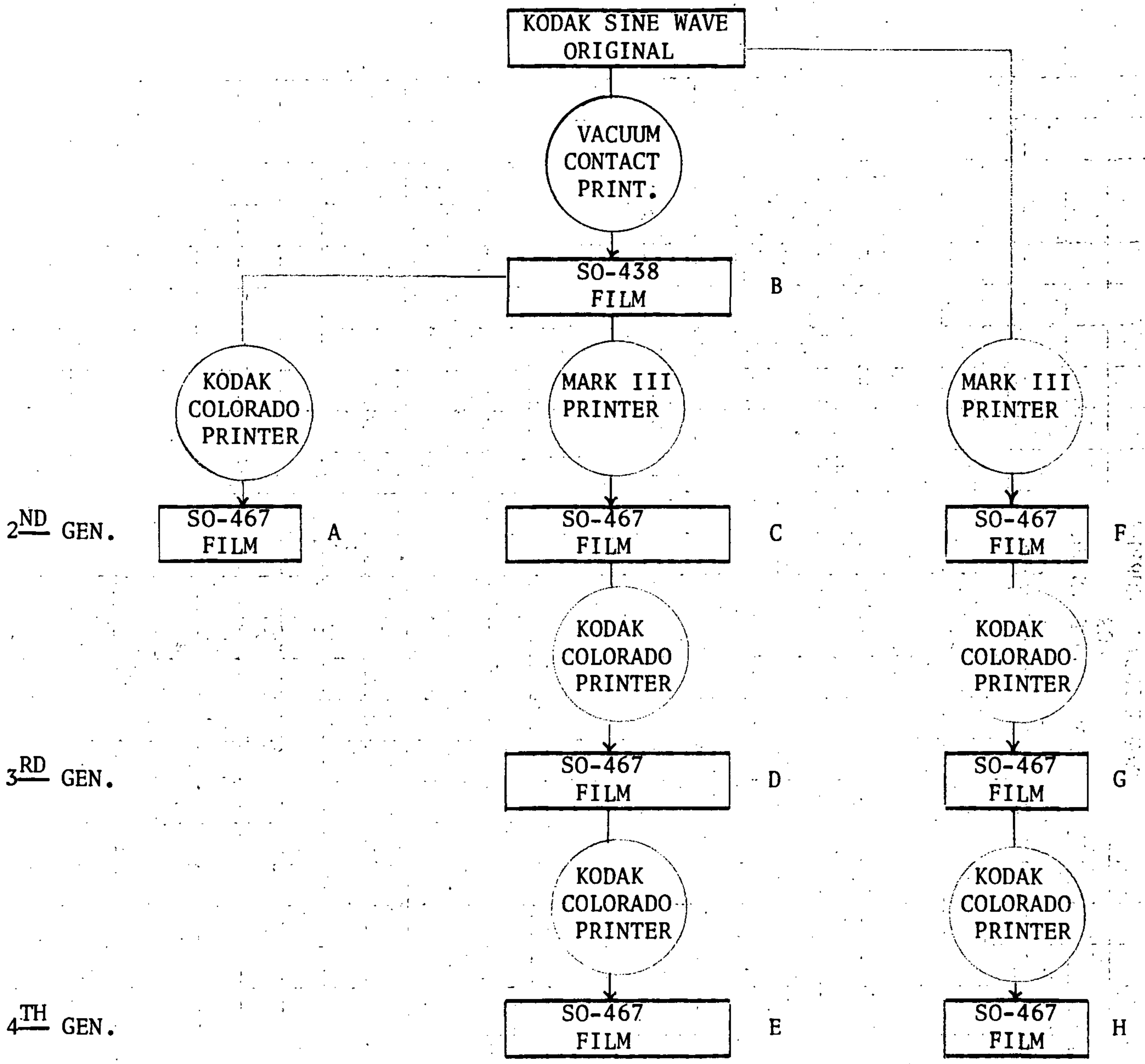

TRANSMISSION CURVES
FOR
COLORADO PRINTER
FIGURE 17
CORNING
FILTERS
RED 2412
GREEN 9782
+3486
BLUE 5850
+3389
% TRANSM.
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
800
WAVELENGTH, NM

TABLE III

LABORATORY OPERATIONS FOR GENERATION OF MTF TEST MATERIAL



LETTERS A TO H DESIGNATE THE PRINTING STAGES DURING MICRODENSITOMETRY OF THE SAMPLES AT KODAK.

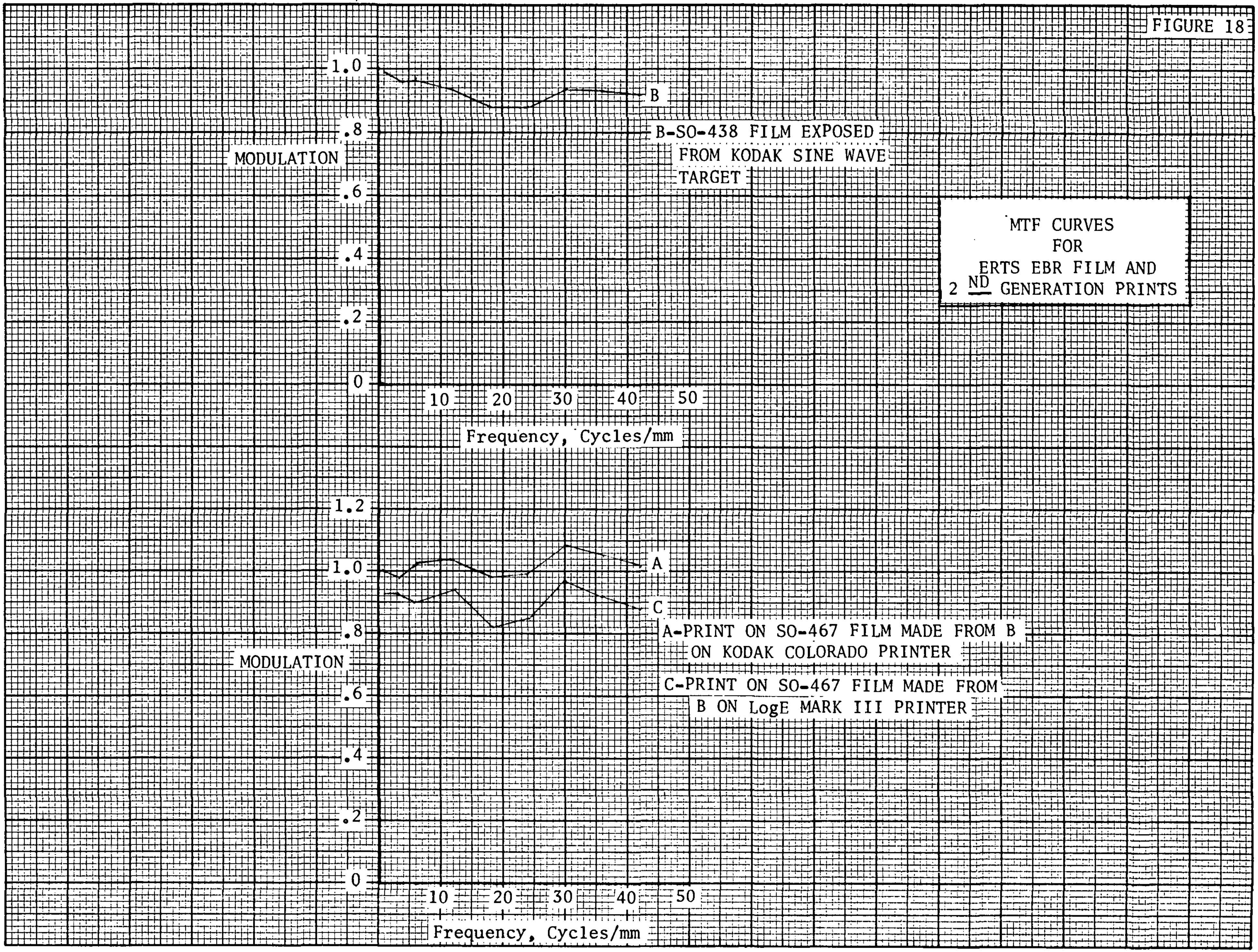
Evaluation of the MTF for items A and C compares the image quality from the LogE Mark III and Kodak Colorado printers, while item E shows the frequency response after the full four stages of duplication. Film H is a similar multi-stage test but without the contribution from the SO-438 EBR recording film.

On three samples at each stage, sine wave images were evaluated at frequencies of 1.5, 3, 6, 12, 18, 24, 30, 36 and 42 cycles/mm. A slit width of 2 x 275 micrometers was used in scanning the film which had been given standard processing in the NDPF machines.

The MTF results shown in Figures 18, 19 and 20 were delivered to Mr. Polger on 20 June 1972. These data are averages of three determinations at each printing stage. Although lines connect each data point, a smooth curve through the points might be equally valid, since the 1-sigma tolerance on any one of these points is ±0.10 for the SO-438 film (B) and ±0.03 for all other stages.

Figure 18 shows that frequencies to 42 cycles/mm are transferred slightly better via the Kodak Colorado printer (A) than through the LogE Mark III printer (C). Also, there might be some enhancement of frequencies near 30 cycles/mm by reproduction on SO-438 film.

K+E 10 X 10 TO THE 1/2 INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.



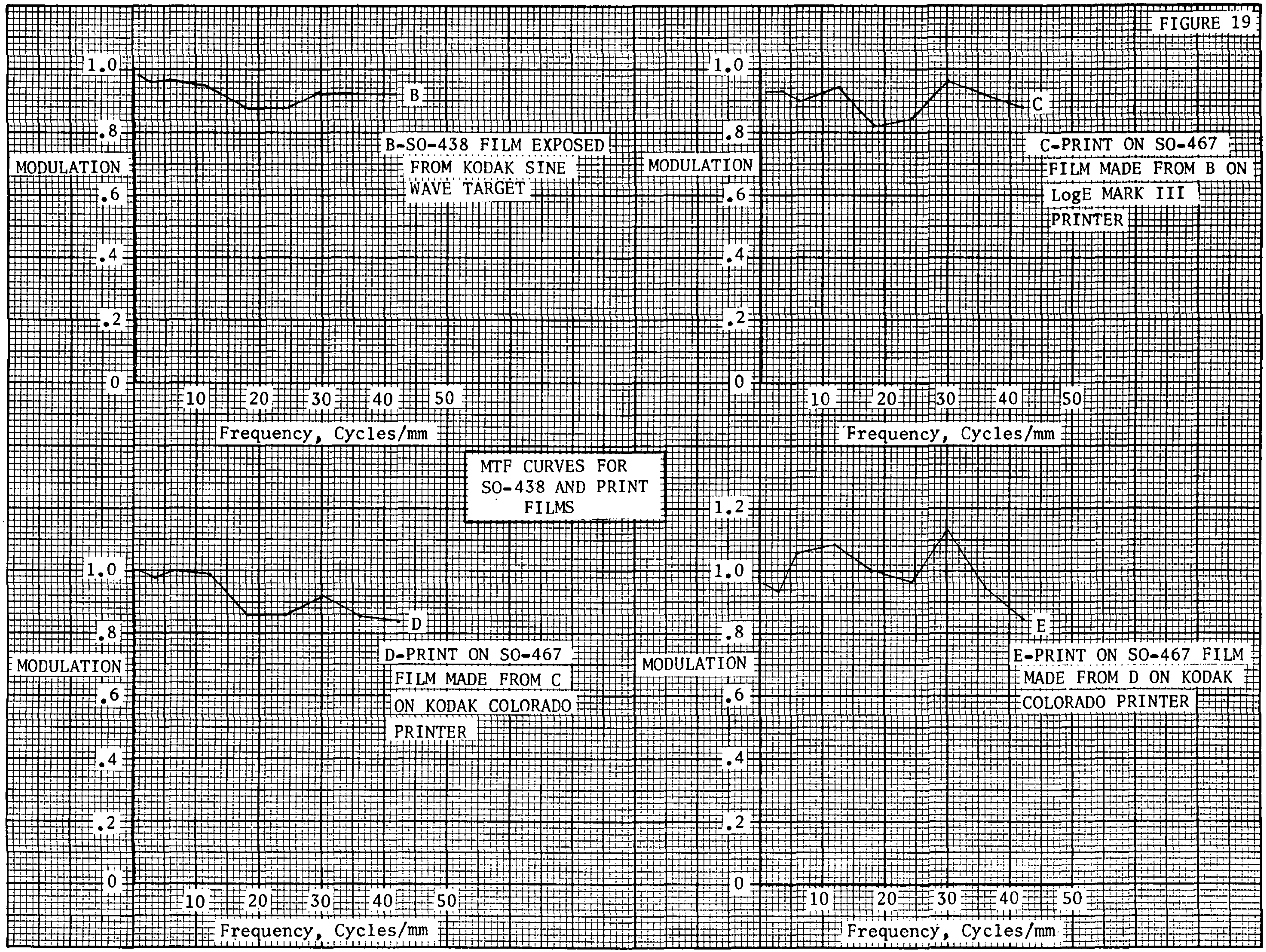


FIGURE 19
MTF CURVES FOR
SO-438 AND PRINT
FILMS
B
B-SO-438 FILM EXPOSED
FROM KODAK SINE
WAVE TARGET
C
C-PRINT ON SO-467
FILM MADE FROM B ON
LogE MARK III
PRINTER
D
D-PRINT ON SO-467
FILM MADE FROM C
ON KODAK COLORADO
PRINTER
E
E-PRINT ON SO-467 FILM
MADE FROM D ON KODAK
COLORADO PRINTER
MODULATION
1.2
1.0
.8
.6
.4
.2
0
10
20
30
40
50
Frequency, Cycles/mm

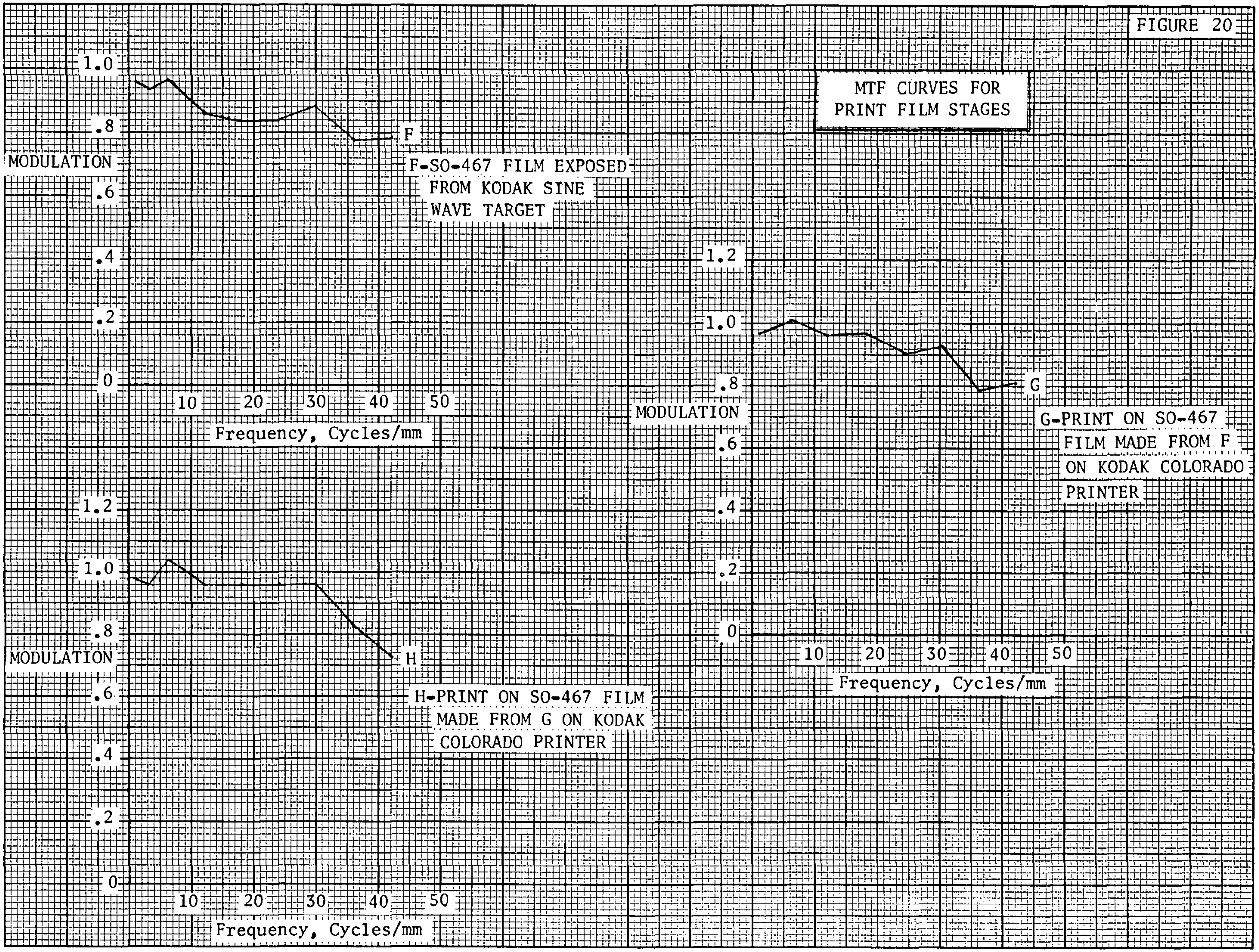


FIGURE 20
MTF CURVES FOR
PRINT FILM STAGES
F-SO-467 FILM EXPOSED
FROM KODAK SINE
WAVE TARGET
G-PRINT ON SO-467
FILM MADE FROM F
ON KODAK COLORADO
PRINTER
H-PRINT ON SO-467 FILM
MADE FROM G ON KODAK
COLORADO PRINTER
F
G
H
MODULATION
MODULATION
MODULATION
1.2
1.0
.8
.6
.4
.2
0
10
20
30
40
50
Frequency, Cycles/mm
Frequency, Cycles/mm
Frequency, Cycles/mm

Figure 19 presents the MTF obtained in the usual duplication cycle at the NDPF. Modulation averages 0.9 over all frequencies and printing stages, but may be dropping in the $4^{\underline{th}}$ generation (E) at the highest frequencies. Again, same enhancement is found at 30 cycles/mm.

Only SO-467 print film stages are shown in Figure 20. These MTF curves are very similar to those in Figure 19 that include SO-438 film. However, the loss in modulation at 36 and 42 cycles/mm is more severe on Figure 20 where the SO-438 film is omitted.

Granularity

NASA furnished eight to twelve film samples with uniform densities ranging from 0.09 to 2.50 for measurement of the granularity produced at each stage of printing. These films were read on a Kodak microdensitometer using apertures of 12.7 and 24. micrometers. A circular trace of 6mm diameter yields an analog RMS reading on the output meter. Single samples at each density were read and are plotted in Figures 21 and 22 after substraction of the instrument RMS value when no sample is in the beam.

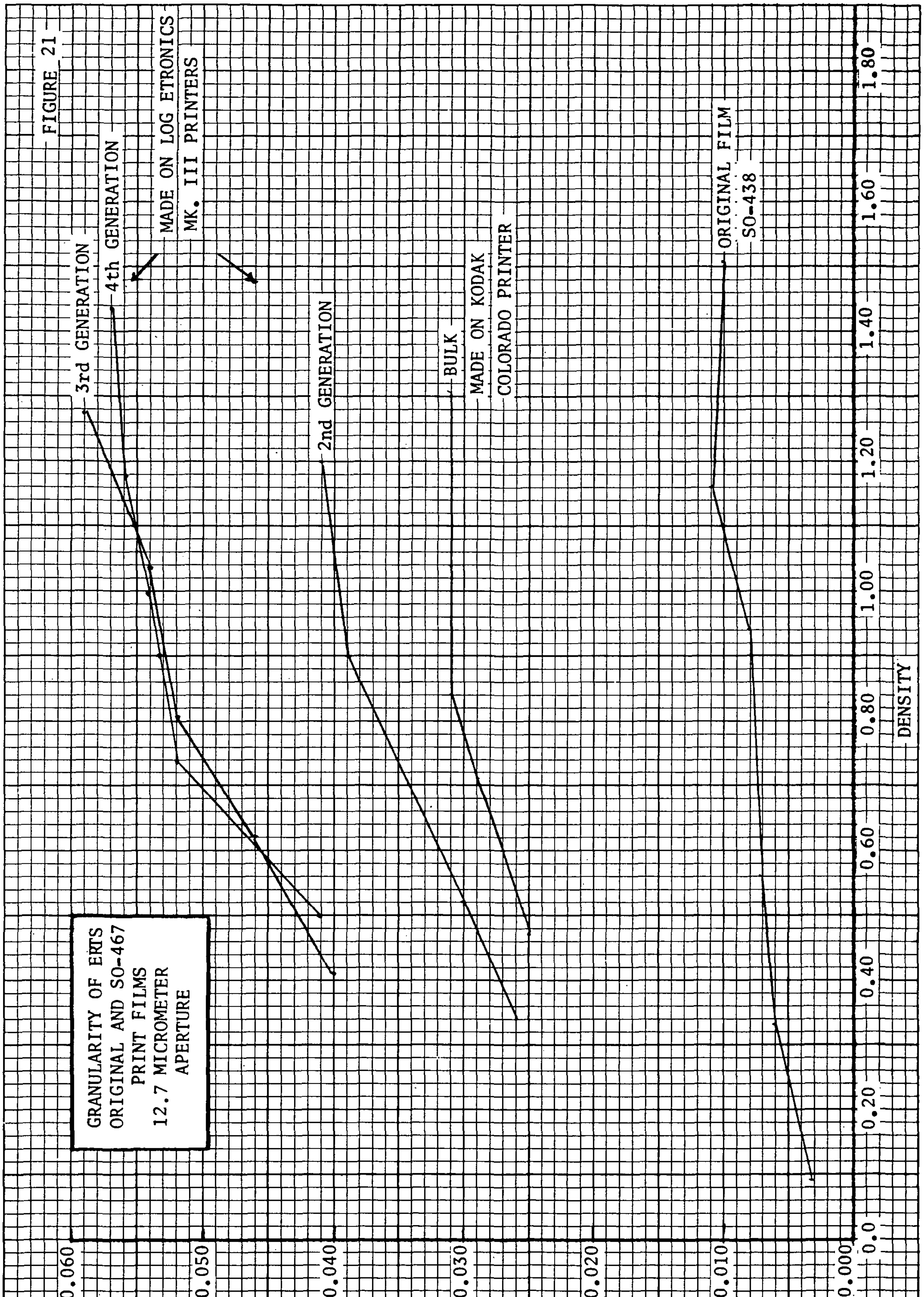


FIGURE 21
GRANULARITY OF ERTS
ORIGINAL AND SO-467
PRINT FILMS
12.7 MICROMETER
APERTURE
3rd GENERATION
4th GENERATION
MADE ON LOG ETRONICS
MK. III PRINTERS
2nd GENERATION
BULK
MADE ON KODAK
COLORADO PRINTER
ORIGINAL FILM
SO-438
GRANULARITY
0.060
0.050
0.040
0.030
0.020
0.010
0.000
DENSITY
0.0
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80

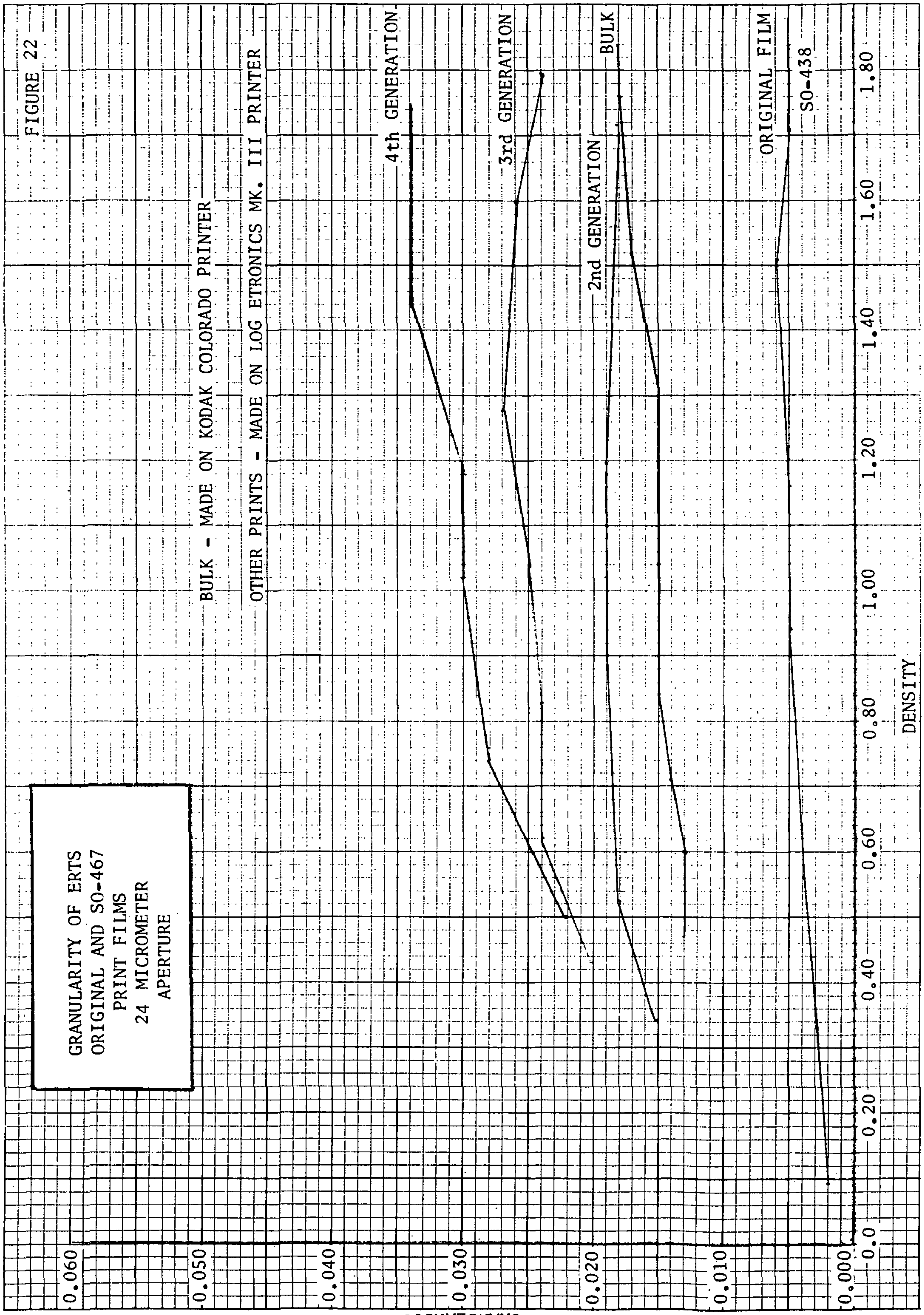


FIGURE 22
GRANULARITY OF ERTS
ORIGINAL AND SO-467
PRINT FILMS
24 MICROMETER
APERTURE
BULK - MADE ON KODAK COLORADO PRINTER
OTHER PRINTS - MADE ON LOG ETRONICS MK. III PRINTER
4th GENERATION
3rd GENERATION
BULK
2nd GENERATION
ORIGINAL FILM
SO-438
GRANULARITY
DENSITY
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.0
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80

As expected, granularity is about twice as large when measured with the smaller aperture, and increases slightly at higher densities. Note that the granularity is the same for third and fourth generation prints measured with an aperture of 12.7 micrometers. This effect is absent in Figure 22 and is caused by production of a grain pattern that in the 3rd generation print is about 12 but less than 24 micrometers in size. When measured with the larger aperture, granularity continues to increase for each printing stage but differences in grain between stages are less pronounced. Grain for the second generation bulk prints is slightly less than for the edited second generation prints, probably because of differences in specularity and contact between the two printers.

Edge Patterns

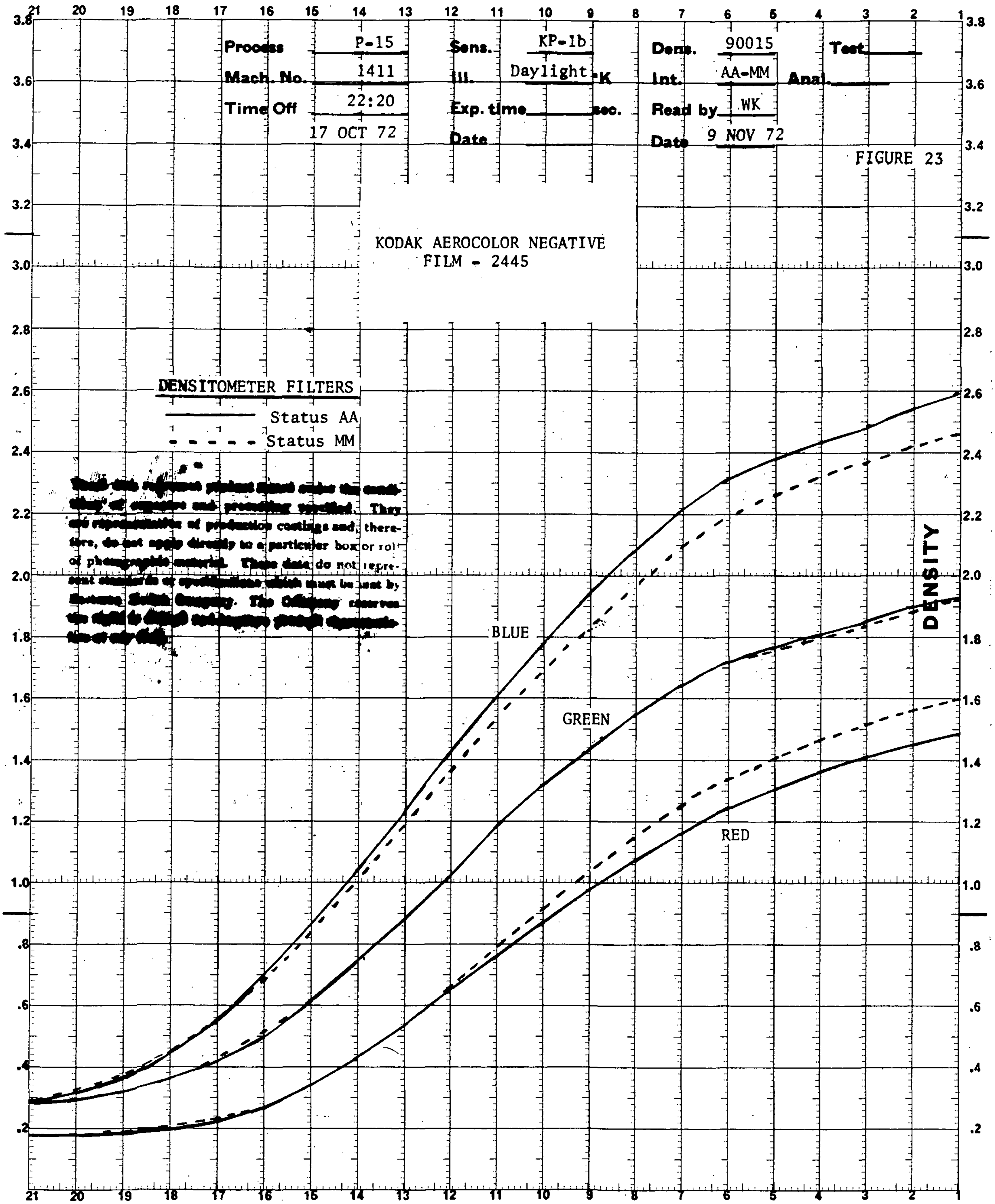
High contrast edges arranged in an L pattern were read but not analyzed by Kodak. Sixty four traces were made on the Kodak microdensitometer using a slit of 2 x 275 micrometers. These traces showed some chemical edge effects, especially on the SO-438 film. Analysis of the chart traces was to be done by engineers at the NDPF.

Sensitometry and Edge Sharpness of Color Films

On several occasions we discussed with NDPF personnel the reproduction of ERTS pictures on color materials. While neither of the ERTS sensors produce a color rendition that shows the scene as it would appear to the eye, it is reasonable to strive for linear tone reproduction in the record for each wavelength band. Furthermore, the gamma and shape of each color record should be the same unless agreement is reached on a desirable deviation from matched records.

An area of concern in obtaining proper sensitometry with color films is the correct matching of densitometer filters and dye spectral densities. Engineers at the NDPF have noted low blue and high red gamma on prints from KODAK Aerocolor Negative Film 2445 (ESTAR Base). This condition can arise if matched gammas are obtained on 2445 film by process adjustments and the gray scale is read using Status AA filters. Note in Figure 23 that densitometry through Status AA filters yields higher blue and lower red gammas than are found if Status MM filters are used.

The reason for this difference is shown in Figures 24 and 25 in which the pass bands of the densitometer filters can be compared to the spectral dye densities of 2445 film. The Status AA


Process P-15
Mach. No. 1411
Time Off 22:20
17 OCT 72
Sens. KP-1b
Ill. Daylight °K
Exp. time_______sec.
Date
Dens. 90015
Int. AA-MM
Read by WK
Date 9 NOV 72
Test______
Anal.______
FIGURE 23
KODAK AEROCOLOR NEGATIVE
FILM - 2445
DENSITOMETER FILTERS
Status AA
Status MM
BLUE
GREEN
RED
DENSITY

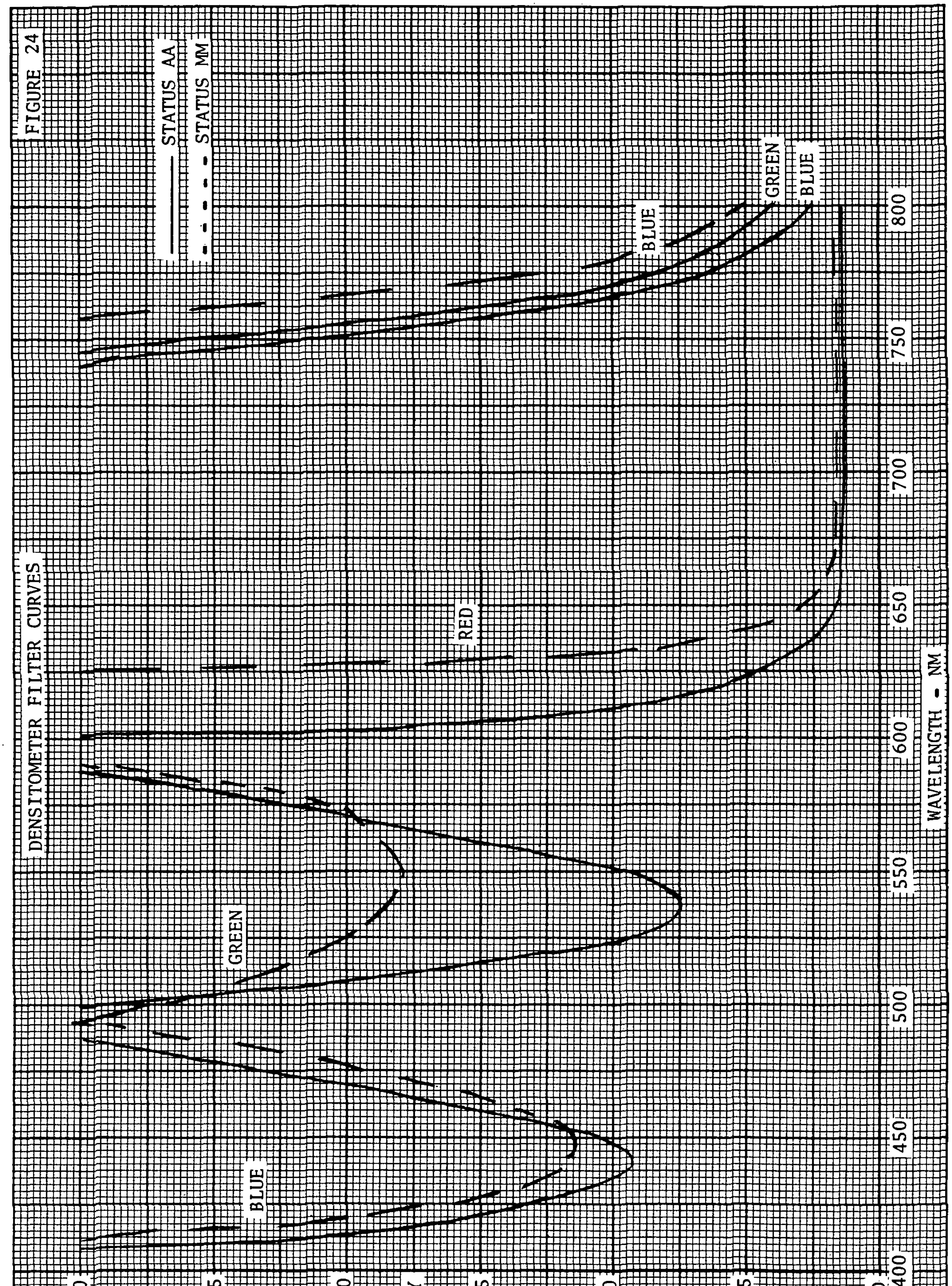


FIGURE 24
DENSITOMETER FILTER CURVES
STATUS AA
STATUS MM
BLUE
GREEN
RED
GREEN
BLUE
BLUE
DENSITY
3.0
2.5
2.0
1.5
1.0
0.5
0
400
450
500
550
600
650
700
750
800
WAVELENGTH - NM

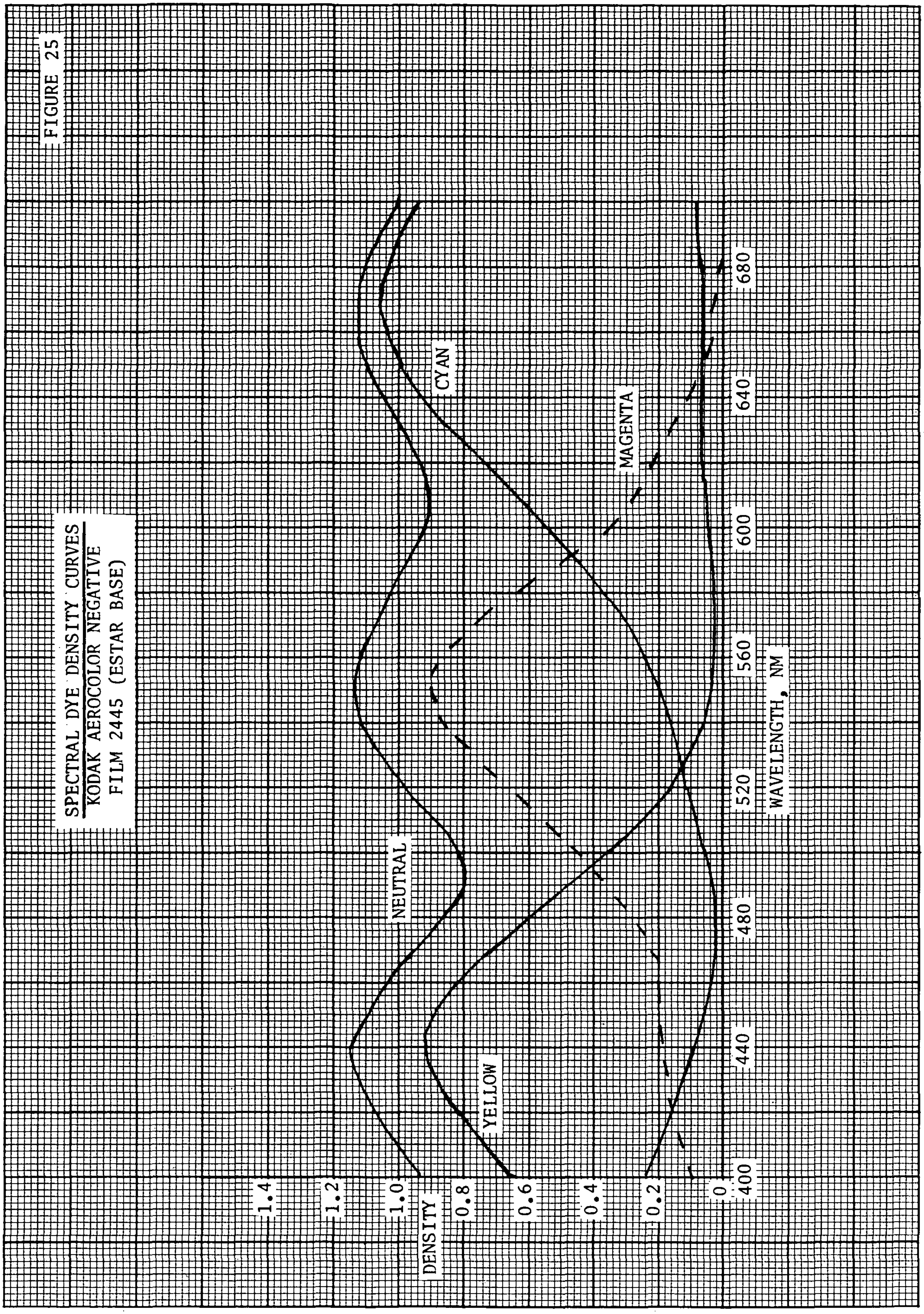
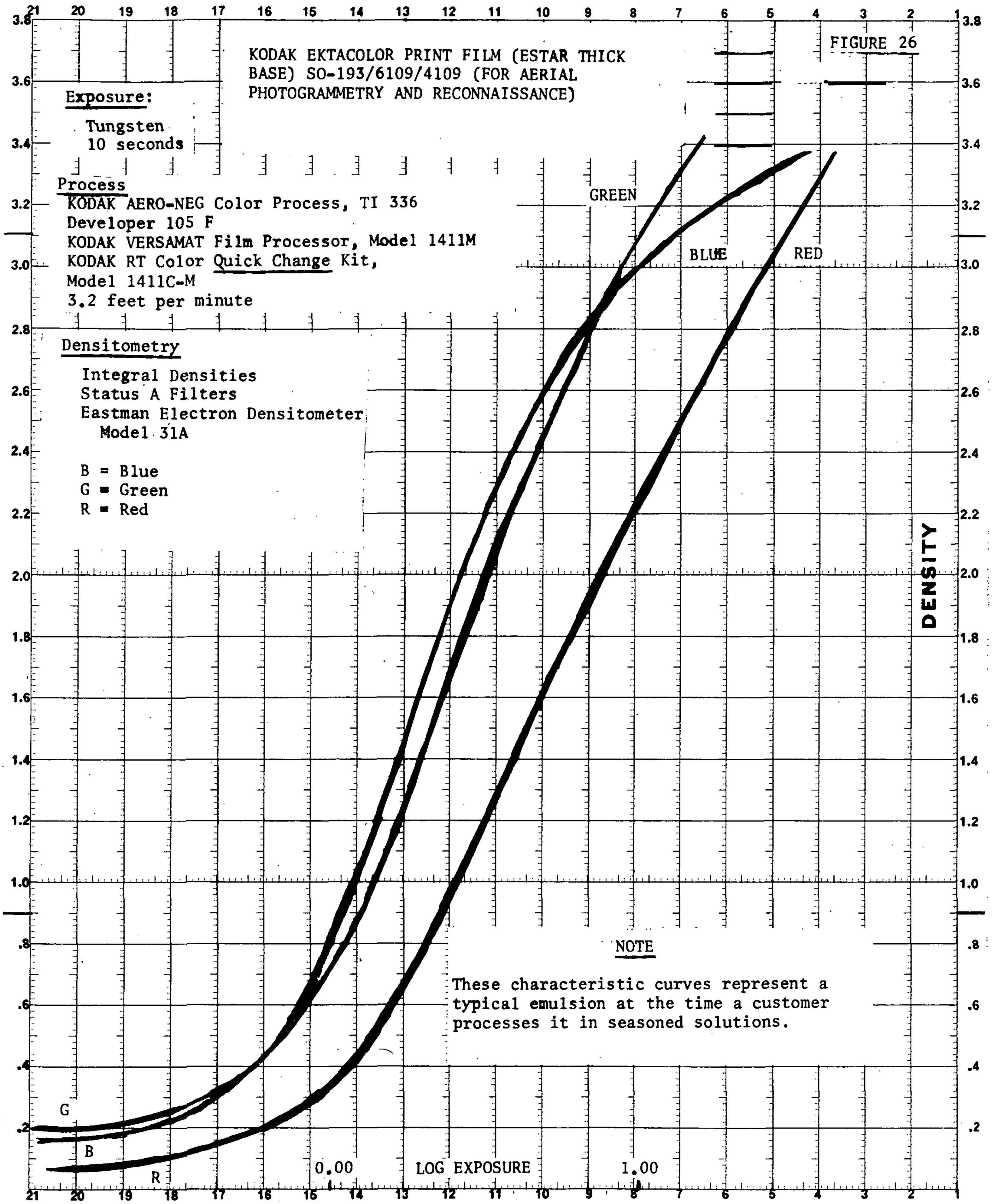


FIGURE 25
SPECTRAL DYE DENSITY CURVES
KODAK AEROCOLOR NEGATIVE
FILM 2445 (ESTAR BASE)
CYAN
MAGENTA
NEUTRAL
YELLOW
DENSITY
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
400
440
480
520
560
600
640
680
WAVELENGTH, NM

blue filter reads nearer the peak density of the yellow dye record, while the Status MM red filter is nearer the peak of the cyan dye density curve. Density readings taken near the peak absorption of a dye yield the maximum gamma for that record. Status MM filters have been designed to give printing densities, i. e., they produce curves showing the approximate relationship of the dye records as seen by the print film. If gray scales read from 2445 film with Status MM filters show mismatched gammas, this condition should be corrected without making a compensating change in the characteristic curve for the print film.

The three color records for KODAK Ektacolor Print Film 4109 (ESTAR Thick Base) are fairly well matched for gamma in the typical characteristic curves shown in Figure 26. This product is normally read using Status AA filters which are designed to "see" color film images with approximately the response of the human eye. Gray scales made on 2445 and 4109 films should be examined for matched printing and visual gammas by carefully exposing and measuring the characteristic curves of the actual emulsions used in the NDPF laboratory. Standard Kodak test strips serve very well for process control, but investigation of tone reproduction for a color film requires sensitometry exposed in the laboratory on the operational equipment and films.

Emul. No.__________ Eastman Kodak Company Process Date______



Effect of Atmosphere

A color print system with an overall gamma of 1.0 would reproduce the scene exactly as it appears from the satellite vehicle. This rendition, however, would not show matched gammas for a neutral gray scale on the ground because of the spectrally selective effect of the Earth's atmosphere. Darker areas of the scene are affected by haze to the greatest extent and frequently appear bluish in reproductions of photography exposed from high altitude.

Figures 27 and 28 describe correction curves for the effects of the atmosphere for each of the ERTS sensors. These plots show for average atmospheric and lighting conditions the difference in gamma correction factors between each wavelength band of the sensors. The plots are derived by the Kodak Research Laboratories using a proprietary computer program and data from considerable high altitude photography. It is assumed that a ground object of 10% reflectance is imaged to the equivalent of a film density of 1.00 at which point all the correction curves are equal. For the short wavelength records, brighter objects need less gamma correction while darker objects require more correction.

Edge Sharpness

Mr. A. Shulman at GSFC questioned the contribution to color fringing at edges that is caused by light scattering and

Emul. No.________ **Eastman Kodak Company** Process Date________

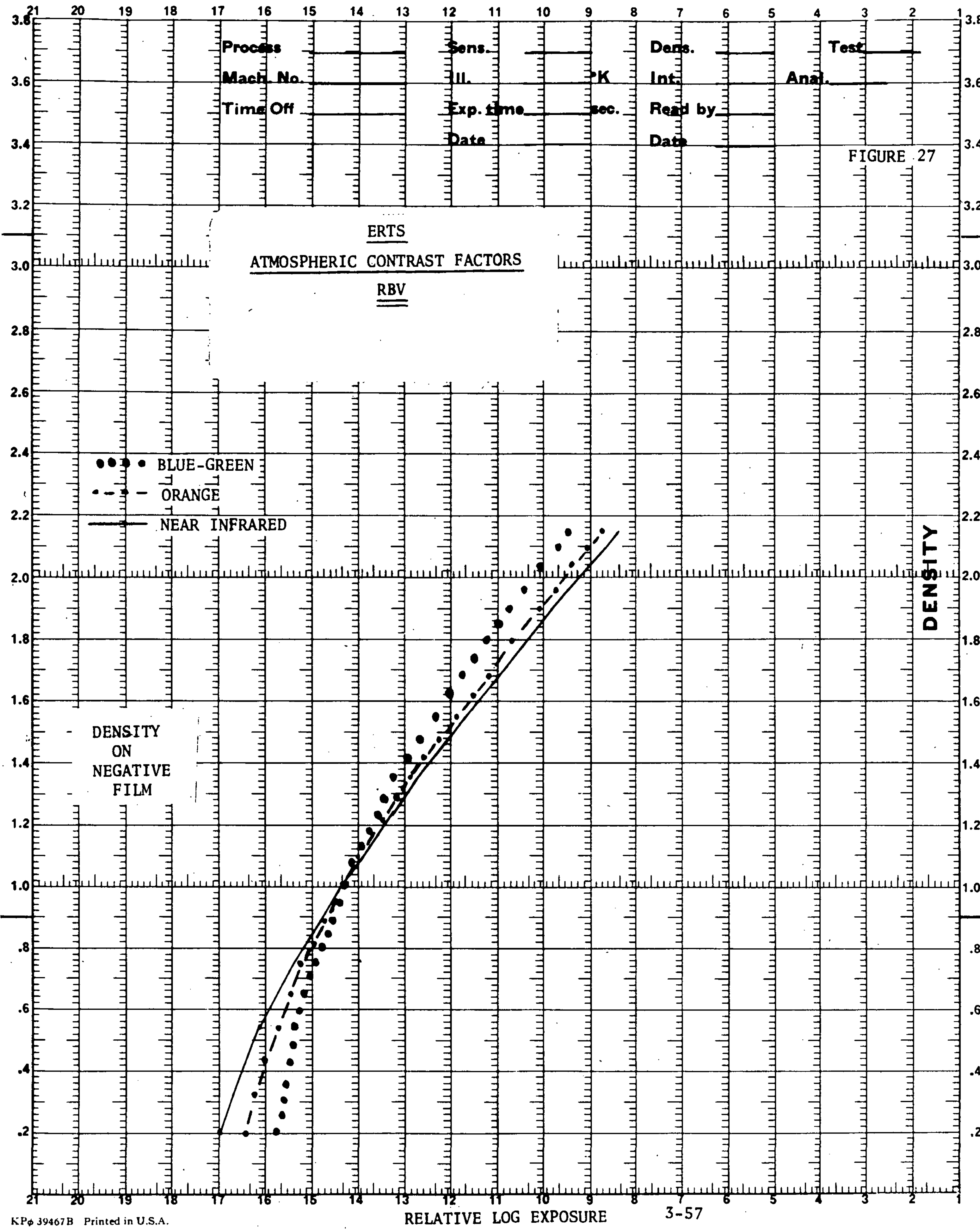


FIGURE 27

Emul. No. ________ Eastman Kodak Company Process Date ________

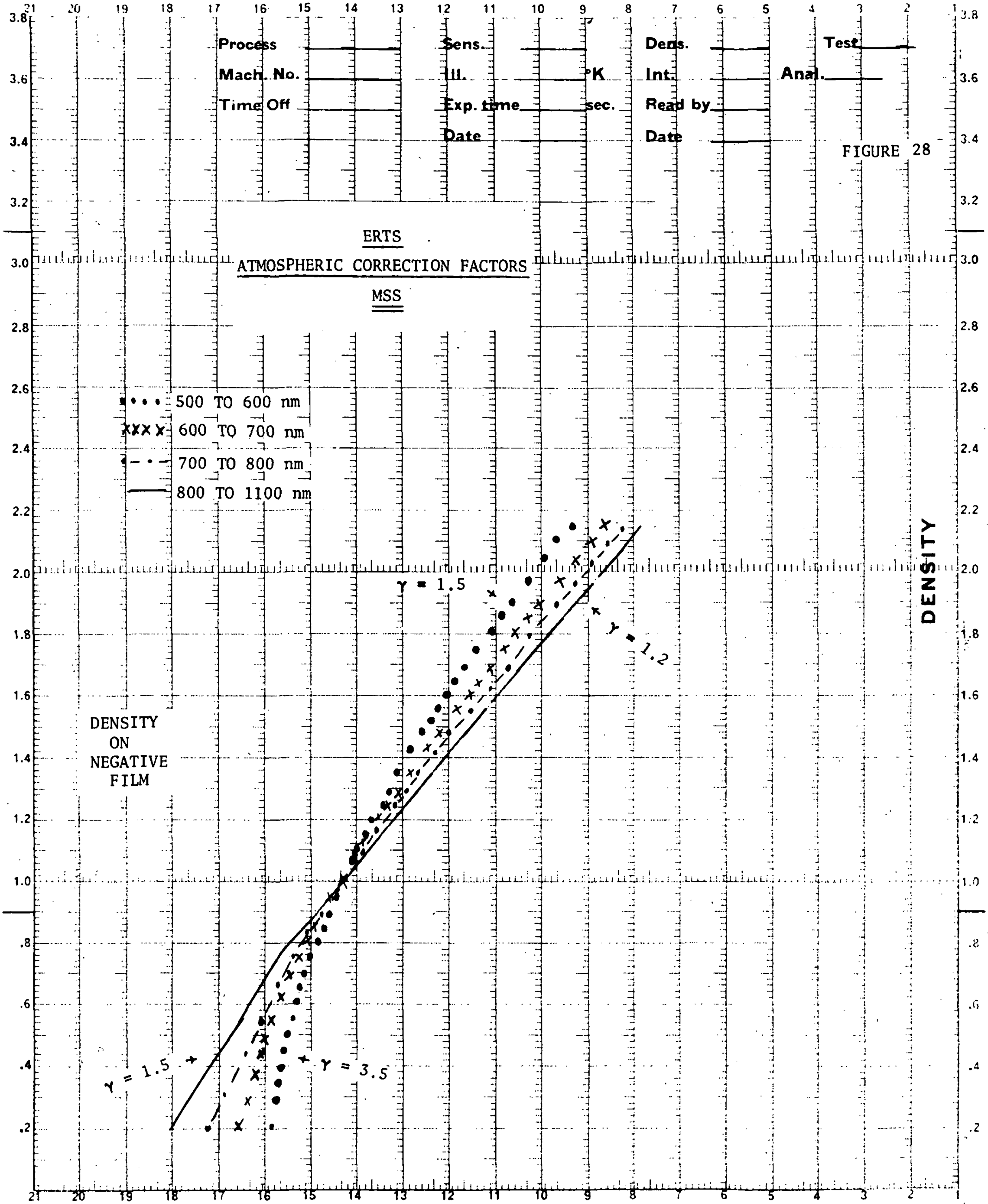


FIGURE 28

developmental effects in the 2445-4109 color film system. The color fringing observed in prints on Kodak 4109 film often exceeds the error tolerance of 22 micrometers.

To study this effect, exposures were made on 2445 and 4109 film of a series of neutral sharp edges of high contrast. Inspection of film cross sections at 100X and 200X showed a red fringe of 10μ width on 4109 film and, on 2445 film, fringes of 5μ to 15μ in the magenta and cyan layers, respectively. When the processed edge images on 2445 film were printed onto 4109 film in the Kodak Colorado Printer, a near-neutral fringe of about 5μ was produced. Apparently, the arrangement of dye layers and interaction of factors contributing to image fringing yield some cancellation of edge fringing in this color film system. The observed 5μ fringe is a small factor compared to registration errors or image distortion that occurs in producing the prints.